







# Steam Economy in the Sugar Factory

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TRANSLATED FROM THE GERMAN EDITION

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## TRANSLATOR'S PREFACE.

IN preparing this book the translator has had in mind primarily the dissemination of information relative to the methods resorted to in the older sugar producing countries. His own needs, as well as those of his staff, concerning the proper distribution and management of steam in sugar factories, for the purpose of effecting economies in the same, have also been an incentive towards its publication.

After devoting many years to the designing of cane sugar apparatus and factories, he engaged in the beet sugar industry, and, finding no books in the English language which would answer his purpose, he undertook the translation of Mr. Abraham's work, which, to his mind, is, up to the present, the best work on the subject.

Since making the translation of this book several years ago, the writer has had the advantage of visiting typical beet sugar factories throughout Italy, Austria-Hungary, Germany, Belgium, Holland, France and Spain, giving special attention to those which elaborate white sugar, and has become more fully convinced of its value and of its profitable application to the methods resorted to in the United States.

He hopes, therefore, that it will meet a real want in all sugar factories and perhaps also be of some little assistance to those technical schools which have a course in Sugar Engineering.

English standards being commonly used in this country for the determination and calculation of the calorific value of fuels and the capacities and heating surfaces of apparatus, the formulas and tables in the German book have, for convenience, been converted into these standards.

In conclusion, the translator expresses the hope that the publication of this work, written during the spare moments of a very active engineering life, may be of assistance towards making clear some of the considerations, both technical and practical, which are necessary in the design and construction, as also in the operation, of sugar apparatus, and, in this way, contribute towards promoting the application of scientific principles to the many problems presented to the sugar men of to-day.

Although the work has been carefully checked, errors may have crept in in printing, and he will be obliged for any notification of these.

E. J. BAYLE.

DENVER, COLO., *August*, 1912.

# STEAM ECONOMY IN THE SUGAR FACTORY

## INTRODUCTION.

WHEN considering the subject of this book and its scope, it occurred to me that it would be better to select one method of elaboration and to consider fully this one method, accompanying the discussion of the same with as many examples as possible. I selected the elaboration of white crystal sugar with two products, as it is carried on throughout Russia and will probably also be carried on elsewhere in the future. In order to be understood, I will describe the process briefly in a general way.

The *raw juice*, having been heated to 176–185° F., is treated with from 2% to 4% lime and generally saturated with three intermediate filtrations of graded stages, and usually the last  $\frac{1}{2}\%$  of lime is added before the *second saturation*.

The temperatures are dealt with very differently in the *first* and *second saturations* and this appears to be of little importance with sound beets and normal work. The *third saturation* is more often carried on with sulphurous acid. After the *scum presses* generally come *refillers*. Previous to its entrance into the *evaporating station*, the juice, almost without exception, is filtered twice and generally boiled thereafter before the final filtration. Where the thin juice has not been sulphured,



this is more frequently done with the *intermediate* (half-concentrated) *juice*. There are, however, some factories which secure the brightest, white crystals without sulphuration.\*

Nowadays, the first product is, with good reason, generally spun off warm, i.e., immediately after its discharge from the *pans*. As soon as the *centrifugal* is at full speed, it is washed with a second product, which is somewhat diluted (40 to 60° Brix) and then with steam. The finished white sugar which comes warm from the *centrifugals* is conveyed into a cooling and drying drum, which commonly has a sieve at its end, and then goes into the bag.

The discharge is usually divided automatically into two and at times three grades.

The higher grade discharge is collected usually in such quantity (and brought back into the process), that it is possible, without boiling the first product very stiffly, to obtain a green syrup, of not over 74% purity. Before being dropped the first product is thinned down in vacuo with about 10% of previously heated second product and then dropped into the mixer.

The second product is boiled to crystals, agitated for from three to five days and spun off at about 113° F. without steam. Ordinarily there is given to the very

\* For a long time it was not clear to me at which point it would be best to introduce SO<sub>2</sub>. I believe I have reached the final conclusion, that the saturation of the intermediate juice before the last body of the evaporators (at from about 40 to 50° Brix.) is best, provided that it be thoroughly filtered before and after sulphuration. Assuredly the filtration preceding appears to be of great importance.

stiffly boiled second product in vacuo before the dropping, and if need be also in the mixer, an addition of hot third product, according as the masseculite thickens.

This is done in order to constantly keep farther apart the somewhat softer crystals, so that they may float freely and thus be protected against grinding, and to prevent the formation of small grains. The raw sugar from the second product is dissolved and brought back into the process. When it is intended to produce the best quality of crystal sugar, from not too favorable beet material, it would be necessary to proceed more cautiously with the reintroduction of the green syrup.

One must be contented with a higher purity green syrup from the first product and thus secure a correspondingly higher second product, which results in a greater amount of the hot third product in the vacuum pan and the mixer, in order to sufficiently lower the purity quotient and to give the crystals the proper protection, which is more certain to occur with a crystal content of not over 40% to 45%.

The green syrup from the second product, as it comes from the centrifugals, is sometimes filtered without dilution, after having been properly heated, which seems to be a very rational practice. A previous chemical treatment, as it is sometimes met with, appears to have no greater advantage than such a simple filtration.

As regards the reintroduction of the green and of the dissolved raw sugar, a great difference of opinion prevails. Its introduction into the *second saturation* is the more common practice; recently also the special treatment

with lime and carbonic acid, its addition to the intermediate juice after being filtered, and the sulphuring of the whole.

To me it seems most important that the green syrup and solutions of raw sugar, which always contain some superheated products, should be somewhere thoroughly boiled with lime. The simpler and the cheaper this can be accomplished, the better.\*

Whether the methods of work be the one or the other, the conclusions to be drawn always remain the same. The following tables also, except 13, are applicable to every method of operation.

With the given tables any one can figure out for himself the consumption of steam for each individual case according to the methods outlined, or he can read it directly from the tables.

In the same way every departure from the common method of operation as regards steam consumption can be easily determined.

In the first place, I will explain the *steam consumption* of the *individual stations*, elucidate the *conditions* which influence this consumption, and then dwell upon the *systems* for utilization of steam, which, independently of the individual use, have for their aim the *reduction* of the *total steam* consumption.

While I give a very short guide for the figuring of heating surfaces, I have intentionally avoided giving definite information relative to coefficients of transmission for each separate station, since they are change-

\* For further detail refer to page 26.

able and very dependent upon the details of construction and the methods of operation.

In any sugar factory it is not difficult to determine the coefficients for this or that station under the prevailing conditions. The designer of a new apparatus must have such experience as to enable him to see his way clear in any single case.

In general it should be recommended, not to rely too much upon the information to be found in literature, as it has too often the imprint of favoritism. When the information comes from inventors this is a matter of course. Or else the very best information is given in order not to cast any reflection on the user by insinuating that he did not know how to keep the apparatus in the proper operating condition.



## THE STEAM CONSUMPTION OF THE INDIVIDUAL STATIONS.

### I. DIFFUSION.

IN the process of diffusion, cossettes at a temperature of from 32 to 60° F. are introduced, and raw juice at from 68 to 104° F. is drawn off; fresh water of varying temperature is introduced and the pulp and the battery waste water are discharged at a temperature only a few degrees higher than that of the fresh water.

There are two reasons for the consumption of heat at this station: *First*, the loss of heat through the radiation from the cells and accessories, calorizers, pulp strainers and measuring tanks. *Second*, the fact that in the products (juice and watery pulp) of diffusion, there is always more heat than in the introduced (cossettes and fresh water) materials.

Let us assume:

100 pounds of cossettes introduced;

$t_r$  = temperature of cossettes introduced;

$c$  = heat capacity of cossettes for diffusion without rinsing water;

$W$  = per cent water used;

$t_w$  = temperature of water used;

$S$  = per cent of soaked cossettes and diffusion water  
(as is contained in the diffusion cell before its discharge);

## STEAM CONSUMPTION OF INDIVIDUAL STATIONS 7

$n^\circ$  = difference between temperature of cell at discharge and temperature of water used;

$100 + D$  = per cent draw of diffusion juice;

$t_d$  = temperature of diffusion juice;

$c^1$  = heat capacity of juice;

$V$  = heat loss through radiation;

$l$  = heat capacity of the water-soaked pulp;

then the heat consumption for diffusion can be expressed as  $x$ .

Whence:

$$x = V + (100 + D)c^1t_d + S(t_w + n) - (100ct_r + Wt_w). \quad (1)$$

which means that the heat consumption equals the loss through radiation, plus the difference in the quantities of heat which are present in the products and the materials of diffusion (above  $32^\circ \text{F}$ ).

Since the weight of the materials of diffusion (water and beets) must naturally be equal to the weight of the product (juice and pulp), the following equation can then be written:

$$100 + W = (100 + D) + S,$$

hence

$$W = D + S \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If we set down in equation (1) instead of  $W$  its value out of (2) we have

$$x = V + Sn + 100(c^1t_d - ct_r) - D(t_w - c^1t_d). \quad (3)$$

This equation permits the exact determination of the heat consumption of diffusion from the known values introduced therein.

For practical purposes we can say that

$$S = 200 \text{ and } c = c^1 = 0.9^*$$

$$\text{Then } x = V + 200n + 90(t_d - t_r) - D(t_w - 0.9t_d), \quad (4)$$

from which it is apparent that the consumption of heat in the diffusion is lower the less the temperature difference between the juice and the cossettes, the warmer the introduced water and the colder the drawn-off juice. This last equation shows likewise that as long as the temperature of the water is higher than 0.9 times the temperature of the juice, the heat consumption diminishes with the increased draw of the battery.

The loss of heat,  $V$ , occasioned by radiation can be calculated approximately for every given diffusion and all conditions of work, with due regard to the radiating surfaces and their temperatures, with the assistance of existing tables (Hausbrandt), or it can be ascertained by means of direct experiments. Such determinations

\* Assuming that the heat capacity of the juice equals the sum of the heat contained in the water and the heat contained in the sugar, then the specific heat can be calculated from the formula  $\frac{B \times 0.301 + (100 - B)}{100}$  in which  $B$  = degrees Brix and 0.301 equals the heat capacity of the sugar according to Kopp.

From this equation the following values are obtained:

Degree Brix of solution	10	20	30	40	50	60	70	80	90
Heat capacity	0.03	0.86	0.79	0.72	0.65	0.58	0.51	0.44	0.37

In fact it is even somewhat lower because of the contraction during the process of dissolving and because of the lower heat capacity of the nonsugar.

For this reason it is not permissible, as usual, to make the heat capacity of the juice equal to unity.

were made by Czerny and Hauner and they found  $V = 888$ , as against Shaper only 342. Naturally these figures must be subject to great variations, according to the size of the diffusion battery and the existing insulation. The high figure of Czerny and Hauner is made plain by the fact that the determination was carried on with a very small battery (29.6 cubic feet).

The difference in temperature  $n$  between the water and the pulp discharged depends on the length of the battery and the distribution of the temperature.

The farther the heating is carried from the water end, the smaller  $n$  will be and vice versa. This can vary in limits between  $2^\circ$  and  $9^\circ$  and must be determined by means of simultaneous measurement of the temperature of the water and the temperature at the center of the diffusion cell before discharging.

In order to find the steam consumption,  $X^1$ , from the heat consumption per 100 pounds of beets, it suffices to divide the result of equation (4) by the number of heat units, which are carried over per pound of steam for the existing conditions in the diffusion, namely, about 970 B.t.u.'s, whence

$$X^1 = \frac{V}{970} + \frac{200n}{970} + \frac{90(t_d - t_r) - D(t_w - 0.9t_d)}{970}. \quad (5)$$

The first member of this equation gives the steam loss occasioned by the radiation, the second the loss through the useless heating of the contents of the last diffusion cell, and the last the profitable steam consumption, which is of benefit to the stations next following. If we



TABLE 1.

*Steam and Heat Consumption for Diffusion of 100 Pounds of Beets.*

Draw.	100%					110%				
Temperature difference between the juice and the cossettes.	Difference between the temperature of water and 0.9 the temperature of juice ( $t_w - 0.9 t_d$ ).									
	0	10	20	30	40	0	10	20	30	40
$t_d - t_r$	Steam consumption per 100 pounds beets; the total heat in B.t.u.'s below.									
10°.....	2.93	2.93	2.93	2.93	2.93	2.93	2.83	2.72	2.62	2.52
	2844	2844	2844	2844	2844	2844	2744	2644	2544	2444
	3.86	3.86	3.86	3.86	3.86	3.86	3.80	3.70	3.60	3.45
	3744	3744	3744	3744	3744	3744	3644	3544	3444	3344
30°.....	4.78	4.78	4.78	4.78	4.78	4.78	4.68	4.57	4.47	4.37
	4644	4644	4644	4644	4644	4644	4544	4444	4344	4244
40°.....	5.71	5.71	5.71	5.71	5.71	5.71	5.60	5.50	5.40	5.30
	5544	5544	5544	5544	5544	5544	5444	5344	5244	5144
50°.....	6.63	6.63	6.63	6.63	6.63	6.63	6.54	6.43	6.33	6.22
	6444	6444	6444	6444	6444	6444	6344	6244	6144	6044
60°.....	7.57	7.57	7.57	7.57	7.57	7.57	7.46	7.36	7.25	7.15
	7344	7344	7344	7344	7344	7344	7244	7144	7044	6944
70°.....	8.50	8.50	8.50	8.50	8.50	8.50	8.40	8.30	8.19	8.08
	8244	8244	8244	8244	8244	8244	8144	8044	7944	7844
Draw.	120%					130%				
Temperature difference between the juice and the cossettes.	Difference between the temperature of water and 0.9 the temperature of juice ( $t_w - 0.9 t_d$ ).									
	0	10	20	30	40	0	10	20	30	40
$t_d - t_r$	Steam consumption per 100 pounds beets; the total heat in B.t.u.'s below.									
10°.....	2.93	2.72	2.52	2.32	2.11	2.93	2.62	2.32	2.00	1.69
	2844	2644	2444	2244	2044	2844	2544	2244	1944	1644
20°.....	3.86	3.66	3.45	3.24	3.03	3.86	3.55	3.24	2.92	2.62
	3744	3544	3344	3144	2944	3744	3444	3144	2844	2544
30°.....	4.78	4.57	4.37	4.17	3.96	4.78	4.47	4.17	3.86	3.55
	4644	4444	4244	4044	3844	4644	4344	4044	3744	3444
40°.....	5.71	5.50	5.30	5.09	4.89	5.71	5.40	5.09	4.78	4.47
	5544	5344	5144	4944	4744	5544	5244	4944	4644	4344
50°.....	6.63	6.43	6.22	6.02	5.81	6.63	6.33	6.02	5.71	5.40
	6444	6244	6044	5844	5644	6444	6144	5844	5544	5244
60°.....	7.57	7.36	7.15	6.95	6.74	7.57	7.25	6.95	6.64	6.33
	7344	7144	6944	6744	6544	7344	7044	6744	6444	6144
70°.....	8.50	8.30	8.08	7.88	7.67	8.50	8.19	7.88	7.57	7.25
	8244	8044	7844	7644	7444	8244	7944	7644	7344	7044

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assume the total of the two first members equal to 2% (that is, 1944 B.t.u.'s per 100 pounds), which in most cases probably proves correct, then the heat consumption and the steam consumption can be read direct for different conditions from the preceding table.

With partly frozen beets, as happens occasionally in winter, the heat consumption per pound of ice is about 144 B.t.u.'s and the steam consumption about  $\frac{144}{970} = 0.148\%$  higher.

There is contained in the cosettes 10 20 30 40 50 % ice.

The steam consumption is 1.48 2.96 4.44 5.93 7.41 % higher.

The heat consumption is 1440 2880 4320 5760 7200 B.t.u.'s

Up to the present it has been assumed that the diffusion was carried on with only one kind of water. If, for some reason or other, the diffusion is carried on with two kinds of water, i.e., clear or warmer water for diffusing and cold or waste water for drawing off, the heat consumption is exactly the same as if only one kind of water had been used, as the last water plays no part in the diffusion proper. It is only necessary that  $n$  be determined by testing with the first kind of water. If the last cell be emptied with air, the result remains exactly the same, as long as the readings for determining the value of  $n$  are taken previous to the introduction of the air.

## II. HEATERS.

Let again, as before, the draw of the juice be equal to  $100 + D$  per cent, the temperature of the juice before the heating  $t_d$ , after heating  $t$ , its heat capacity  $c^1$ , then the heat capacity per 100 pounds of beets equals

$$c^1 (100 + D) (t - t_d)$$

and the heat consumption, if 970 B.t.u.'s are transferred per pound equals

$$\frac{c^1 (100 + D) (t - t_d)}{970}.$$

According to this the following Table 2 is calculated, in which, for the sake of simplicity,  $c^1$  is set as equal to 0.9.

If for still greater accuracy, instead of  $c^1$  its value  $c^1 = \frac{B \times 0.301 + (100 - B)}{100}$ , wherein  $B$  is the degree

Brix, may be substituted in the formula.

The table shows that with proportionate temperature differences the steam and heat consumption are directly proportional to the draw of the juice.

The steam consumption for intermediate temperatures is easy to determine by the use of Table 2.

EXAMPLE 1. — How much is the steam consumption for the heating of the juice from  $86^\circ$  to  $183.2^\circ$  with 120% draw? The difference  $183.2 - 86 = 97.2^\circ$ .





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For 90° difference, % steam used is . . . . . 10.02

For 70° difference, % steam used is . . . . . 7.79

Then for 7° difference, % steam used is . . . . . 0.779

For 20° difference, % steam used is . . . . . 20.2

Then for 0.2° difference, % steam used is . . . . . 0.022

Then for 97.2° the % steam — Total 10.822

TABLE 2.

*Steam and Heat Consumption of the Heaters per 100 Pounds of Beets.*

		Degrees difference between juice leaving heater and juice entering heater ( $t - t_d$ ).								
Juice draw.		10	20	30	40	50	60	70	80	90
		Steam consumption per 100 pounds of beets. The quantity of heat in B.t.u.'s under same.								
100% . . .	0.93	1 85	2 78	3 71	4 64	5 57	6.49	7.42	8.35	
	900	1800	2700	3600	4500	5400	6300	7200	8100	
110% . . .	1 02	2.04	3 06	4.08	5.10	6.12	7 14	8 16	9.18	
	990	1080	2070	3060	4050	5040	6030	7020	8910	
120% . . .	1.11	2.22	3 34	4 46	5 57	6.67	7.79	8 90	10 02	
	1080	2160	3240	4320	5400	6480	7560	8640	9720	
130% . . .	1 20	2 41	3 61	4 82	6 03	7 25	8.44	9.65	10 85	
	1170	2340	3510	4680	5850	7020	8190	9360	10,530	
140% . . .	1 30	2 60	3 90	5 20	6 40	7 78	8 98	10 38	11.78	
	1260	2520	3780	5040	6300	7560	8820	10,080	11,340	

		Degrees difference between juice leaving heater and juice entering heater ( $t - t_d$ ).						
Juice draw.		100	110	120	130	140	150	160
		Steam consumption per 100 pounds of beets. The quantity of heat in B.t.u.'s under same.						
100% . . .	9 28	10.20	11 12	12 05	12 98	13.91	14.83	
	9000	9000	10,800	11,700	12,600	13,500	14,400	
110% . . .	10 20	11 22	12.24	13 26	14 28	15 30	16.32	
	9000	10,890	11,880	12,870	13,860	14,850	15,840	
120% . . .	11 12	12 23	13.34	14 46	15 58	16.79	17 80	
	10,800	11,880	12,960	14,040	15,120	16,200	17,280	
130% . . .	12 05	13 25	14 46	15 66	16 87	18 08	19.28	
	11,700	12,870	14,040	15,200	16,380	17,550	18,720	
140% . . .	12 98	14 28	15.58	16.88	18 18	19 48	20.87	
	12,600	13,860	15,120	16,380	17,640	18,900	20,160	

### III. THE SATURATION OF THE THIN JUICE.

Whatever may be the subdivisions as regards the saturation of the thin juice (two or three separate stations) and whatever the process may be, it depends, on the whole, on the following steps: (1) The addition (at one or two times) of a determined quantity of milk of lime or of unslacked lime, and then of a corresponding quantity of sweet water from the presses. (2) The saturation in two or three consecutive stages with intermediate filtration. (3) The heating at different intervals, and ultimately to the boiling point.

In order to make the calculations relating to the steam and heat consumption, we will have to evolve first some auxiliary values, which are compiled in the following Table 3.

The saturation gas contains greatly varying quantities of carbonic acid: 14% to 17% by volume, if the gas be taken out from the rear of boilers, fired with wood; 20% to 32%, if from lime kilns. According to its weight, the contents of carbonic acid are greater, as indicated by line 2, wherein the weight of a cubic foot of  $\text{CO}_2$  is equal to 0.1226 pounds and of the other gases equal to 0.0814 pounds. Of that amount of carbonic acid, only a portion is absorbed by the juice, from 45% to 65%, that much the less, the warmer the juice and the lower the original content of carbonic acid.

As regards this, line 3 gives the approximate percentage by weight of the consumed  $\text{CO}_2$  and line 4 that portion of the carbonic acid contained in the gas which is

**TABLE 3.**  
*Conditions Concerning Saturation.*

1	Volumetric content of carbonic acid	cc.	15	20	25	30
2	Weight content of carbonic acid (approx.)	cc.	21	28	34	39
3	Consumed content (by weight) CO <sub>2</sub>	cc.	10	15	20	25
4	Per 100 CO <sub>2</sub> utilized (approx.)	cc.	48	53	59	64
5	Precipitation of the lime requires saturation gas (dry) pounds		7	8	9	10
6	Of which will be consumed by the juice	pounds	0	0	0	0
7	There escapes out of the saturation (dry)	pounds	0	0	0	0
8*	Corresponding volume at 32° F.	cu. ft.	83.4	52	45	3
9	Corresponding volume at 167° F., saturated with steam, cu. ft.		171	108	76	56
10	Corresponding volume at 176° F., saturated with steam, cu. ft.		208	126	80	66
11	Corresponding volume at 185° F., saturated with steam, cu. ft.		254	160	112	84
12	Corresponding volume at 194° F., saturated with steam, cu. ft.		338	226	158	119
13	Corresponding volume at 203° F., saturated with steam, cu. ft.		678	457	300	225

Figures given on lines 5 to 13 inclusive are for each pound of CaO.

\* 1 cubic foot escaping gas at 32° F. weighs 0.0848 lbs.



thereby utilized. Naturally the values of lines 3 and 4 cannot always be considered as fixed, as these depend not only on the temperature and carbonic acid content, but also on the column of the juice, the distribution of gas, the alkalinity and the quality of the juice.

Since, for the neutralization of a pound of  $\text{CaO}$ ,  $\frac{44}{56} = 0.786$  pound of  $\text{CO}_2$  are necessary, then the weight of the saturation gas which is requisite for the precipitation of one pound of lime is found by dividing  $\frac{44}{56} \times 100$  by the percentage (by weight) of  $\text{CO}_2$  utilizable. The result is given on line 5.

After subtracting the actually consumed 0.786 pound  $\text{CO}_2$  from the numbers on line 5, the quantity of gas is found which, considered as dry, escapes out of the saturation. This is given on line 7.

In order to pass from the weight of the escaping gas to its volume at 32 degrees, the values must be divided by the weight of one cubic foot, which is assumed as being 0.0848 pound. These are the values of line 8.

These quantities of escaping gas are also heated up to the temperature of the juice and at the same time saturated with steam. These two circumstances occasion an expansion of the gas according to the equation  $V^1 = V \left( \frac{t + 459.2}{491.2} \right) \left( \frac{29.92}{29.92 - s} \right)$ . Here  $V$  is the volume of the dry gas at 0 degree (also corresponding to the values of line 8),  $t$ , the temperature after leaving the juice, and  $s$ , the tension of the steam at  $t^\circ$ . According to this formula lines 9 and 13 are computed.

The steam consumption during the process of satura-

tion is made up of several items which are hereafter set forth in their regular order.

(A) The heating of the juice from the temperature at which it leaves the raw juice heater to that at which it enters the evaporating station. This value is easy to find with the help of Table 2, page 13, or, more exactly, according to the formula:

$$\frac{B \times 0.301 + (100 - B)}{100} \times \frac{(100 + D) (t^1 - t)}{970},$$

wherein  $B$  is the degree Brix;  $100 + D$ , the quantity of juice from 100 pounds of beets;  $t$  and  $t^1$ , the initial and final temperatures.

(B) The loss of heat through radiation, in the saturation tanks, the scum presses, filters and piping on the way from the raw juice heater to the first body of the evaporators. This loss is, with surfaces sufficiently insulated with felt, equal on an average to a cooling off of the juice of from about 45 degrees to 54 degrees, corresponding to an average steam consumption of 5.5% (5346 B.t.u.'s). Naturally this temperature drop, with its corresponding loss, can be ascertained through special investigation for each given case, and from this the steam consumption can be determined according to Table 2.

(C) The heating of the milk of lime from the initial temperature to the final temperature of the juice, which

is on an average about 135 degrees. Each pound of lime requires on an average four pounds of water, which is introduced partly directly into the lime milk, and partly, as sweet water, into the juice. With a heat capacity of 0.2 in the lime there is required for each pound of lime

$$\frac{(1 \times 0.2) + (4 \times 1)}{970} \times 135 = 0.584 \text{ pounds steam.}$$

If the lime treatment be effected with unslacked lime and the sweetening off with warm water, then the corresponding steam consumption is only  $\frac{1 \times 0.2 \times 135}{970} = 0.027$  per pound of lime, and, therefore,  $0.584 - 0.027 = 0.557$  pounds of steam per pound of lime is saved.

(D) The heating of the saturation gas from an average of 68 degrees, at which temperature it flows into the saturation tank at atmospheric pressure, up to the final temperature at which it leaves the juice. With a heat capacity of the gas of 0.23 the steam consumption heretofore mentioned as necessary for each pound of CaO is determined by multiplying the corresponding values of line 5, Table 3, by  $\frac{0.23(t - 68)}{970}$ , where  $t$  is the final temperature of the gas. The small degree of moisture, in the gas entering the juices, has here been, and will further be, neglected. The following Table 4 gives the loss of steam with reference to one pound CaO.

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TABLE 4.

*Steam Consumption in Pounds for Each Pound of Lime Due to Heating of the Gas.*

Carbonic acid content of the gas (volumetric)	15	20	25	30
Average final temperature of the gas.....	$\left\{ \begin{array}{l} 167^{\circ} \\ 176^{\circ} \\ 185^{\circ} \\ 194^{\circ} \\ 203^{\circ} \end{array} \right.$	$\left\{ \begin{array}{l} 0.185 \\ 0.201 \\ 0.218 \\ 0.235 \\ 0.251 \end{array} \right.$	$\left\{ \begin{array}{l} 0.123 \\ 0.134 \\ 0.145 \\ 0.156 \\ 0.168 \end{array} \right.$	$\left\{ \begin{array}{l} 0.092 \\ 0.100 \\ 0.108 \\ 0.117 \\ 0.126 \end{array} \right.$
				$\left\{ \begin{array}{l} 0.073 \\ 0.080 \\ 0.087 \\ 0.093 \\ 0.100 \end{array} \right.$

(E) Evaporation of the water in the saturations.

This is one of the main items of steam consumption in the saturation and also causes very often a considerable loss of steam in the factory, which is proved by the clouds of steam escaping from the discharge pipes of the saturation tanks.

Strange as it may seem, this consumption, up to date, has not been considered. The values on lines 9 and 13 of Table 3 give the volumes of gas which leave the saturation under the various conditions. These volumes are saturated with steam.

In accordance with known physical laws, the gases saturated with steam contain exactly as much steam as would be contained in the same volume at the same temperature were no gas present.

For the steam content of a cubic foot at varying temperatures, there are existing tables, e.g., Zeuner's improved table found in most of the handbooks. By multiplying the values in this table by the corresponding figures of lines 9 to 13, of Table 3, the steam contents

of the escaping gas for each pound CaO is found. Inasmuch as we leave out of consideration the small quantity of steam which was contained in the original gas, we can say that this steam was evaporated out of the juice. But, since for this evaporation almost exactly as much steam must be condensed in the heating arrangements of the saturation, if no radiation were to take place, then the resulting figure gives directly the steam consumption sought to be determined through them. These figures are contained in Table 5.

TABLE 5.

*Steam Consumption Due to Evaporation in the Saturation for Each 1% CaO on the Weight of Beets*

Temperature of the escaping gases and steam.	Volumetric contents of the saturation gas in per cent CO <sub>2</sub> .			
	15%	20%	25%	30%
167°	2.58	1.62	1.14	0.86
176°	3.70	2.32	1.64	1.23
185°	5.60	3.53	2.48	1.86
194°	9.49	5.96	4.20	3.15
203°	21.39	13.45	9.46	7.11

(F) Besides the heat consumption there is also a heat production in the saturation because in forming CaCO<sub>3</sub>, chemical energy is transformed into heat. On that account two cases must be distinguished:

- (1) The use of milk of lime, and
  - (2) The use of dry lime.
- (1) According to Thomsen, for each mole-pound of

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$\text{CaCO}_3$ , which is formed from the aqueous solution of the  $\text{Ca}(\text{HO})_2$  and  $\text{CO}_2$ , 33,318 B.t.u.'s are liberated. 1 per cent  $\text{CaO}$  (molecular weight 56) corresponds to  $\frac{33,318}{56} = 594.96$  heat units, which correspond to a sav-

ing of steam of  $\frac{594.96}{970 \times 100} = 0.61\%$ .

(2) According to Thomsen out of every mole-pound of  $\text{CaCO}_3$ , which is formed from dry  $\text{CaO}$  and  $\text{CO}_2$ , 76,482 heat units are liberated. 1 per cent  $\text{CaO}$  corresponds then to  $\frac{76,482}{56} = 1365.7$  heat units, equivalent to a sav-

ing of steam of  $\frac{1365.7}{970 \times 100} = 1.42\%$ .

The defecation with dry lime then saves  $1.42 - 0.61 = 0.81\%$  steam on the weight of beets for each 1%  $\text{CaO}$ , which saving is not taken into account under item C.

By reason of the heat losses and the sources of heat transference *A*, *B*, *C*, *D*, *E* and *F*, thus far investigated, it is easy to calculate the steam consumption of the saturations for every condition by adding the corresponding items, calculated or taken from the tables, for *A*, *B*, *C*, *D*, *E*, and subtracting the value of *F* therefrom. Now, since the items *C*, *D*, *E* and *F* stand in direct proportion to the lime consumption, then in the following Table 6 (for the sake of facilitating the calculation) the sum of the items *C*, *D* and *E* less *F* is given for every 1%  $\text{CaO}$  where milk of lime is used. With dry lime the corresponding figures are diminished by 0.81% in item

*F*, and frequently also by a further 0.55% in item *C*, thus in total  $0.81 + 0.55 = 1.36\%$ .

The values corresponding to the contents of  $\text{CO}_2$  of 15%, 20%, 25% and 30% are computed, the others are to be found by interpolation.

TABLE 6.

*Steam Consumption in Pounds for the Items C + D + E - F, for Each 1% CaO as Milk of Lime.*

Average temperature of the escaping gases and steam.	Volumetric content of the saturation gas in per cent $\text{CO}_2$ .									
	14	15	16	17	18	19	20	21	22	23
167°....	3.10	2.73	2.47	2.24	2.05	1.88	1.71	1.59	1.48	1.38
176°....	4.30	3.87	3.44	3.14	2.88	2.64	2.42	2.24	2.09	1.95
185°....	6.40	5.79	5.22	4.74	4.33	3.97	3.64	3.37	3.15	2.94
194°....	11.00	9.69	8.75	7.95	7.20	6.50	6.00	5.65	5.25	4.90
203°....	24.00	21.61	19.35	17.60	16.00	14.80	13.50	12.50	11.60	10.80
Average temperature of the escaping gases and steam.	Volumetric content of the saturation gas in per cent $\text{CO}_2$ .									
	24	25	26	27	28	29	30	31	32	
167°....	1.28	1.20	1.12	1.06	1.00	0.95	0.90	0.85	0.81	
176°....	1.82	1.71	1.60	1.51	1.42	1.35	1.28	1.21	1.15	
185°....	2.74	2.56	2.40	2.26	2.13	2.02	1.92	1.83	1.75	
194°....	4.58	4.29	4.05	3.81	3.60	3.40	3.21	3.04	2.87	
203°....	10.10	9.55	9.00	8.45	8.00	7.55	7.18	6.85	6.55	

For the determination of the heating surfaces the heat consumption in heat units which is contained in the following table 7 is to be taken into account.

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TABLE 7.

*Heat Consumption for Items C + D + E - F, for Each 1% CaO as Milk of Lime in B.t.u.'s.*

Average temperature of the escaping gases and steam, ° F.	Volumetric content of the saturation gas in per cent CO <sub>2</sub> .							
	14	15	16	17	18	19	20	21
167°	3,004	2,660	2,400	2,180	1990	1,826	1,660	1,547
176°	4,180	3,760	3,338	3,050	2800	2,565	2,350	2,180
185°	6,210	5,620	5,070	4,610	4210	3,700	3,538	3,278
194°	10,680	9,420	8,510	7,720	6980	6,400	5,920	5,425
203°	23,320	20,990	18,790	17,100	1554	14,380	13,200	12,140

Average temperature of the escaping gases and steam, ° F.	Volumetric content of the saturation gas in per cent CO <sub>2</sub> .										
	22	23	24	25	26	27	28	29	30	31	32
167°	1,438	1,342	1242	1167	1089	1030	973	925	875	8277	786
176°	2,030	1,806	1760	1644	1555	1467	1380	1312	1243	1175	1115
185°	3,060	2,860	2665	2400	2330	2195	2070	1964	1865	1778	1702
194°	5,090	4,700	4450	4170	3940	3690	3500	3300	3120	2958	2790
203°	11,270	10,490	9820	9280	8750	8220	7,80	7330	6970	6485	6360

We can now figure the loss for the steam consumption in the saturations occasioned by settling the foam with steam, as is the custom in many factories. This method of breaking the foam is effective but much too costly and irrational, due to the enormous losses of steam frequently occurring at this point, which are entirely incalculable, — as they can vary in the widest degree



in one and the same establishment according to the manipulation, — so this item will not be taken into consideration.

This is merely mentioned because if through no other agency, the foam can be as well beaten down with saturation gas.

EXAMPLE 2. — There is drawn off 120% of juice heated to 176° F. Let the addition of lime, in the form of milk of lime, be 3%; the saturation gas contains 24% CO<sub>2</sub>. Let the average temperature of the saturation be 185° F.; the escaping gases have an average temperature of 176° F. and the finished juice enters into the evaporating system at 203° F. How much steam is consumed on the way from the heater to the evaporators?

(A) The heating of the juice amounts to  $203^{\circ} - 176^{\circ} = 27^{\circ}$ . In accordance with Table 2, the steam consumption for the heating of juice at 120% draw through 20° equals 2.22%, through 70°, equals 7.79%, for 7°, then, 0.779% and for 27°,  $2.22 + 0.779 =$

3.07%

(B) According to the previous assumption . . . . . 5.5%

$C + D + E - F$ , as per Table 6, amount to

1.82% for each 1% CaO with 3% lime, then they

amount to  $1.82 \times 3 =$  5.46%

Total on the weight of the beets 13.96%\*

For the sake of ascertaining quickly the steam consumption in the saturation, under average conditions of work, the following Table 8 is given.

\* For the determination of the heating surfaces of the several stations of the saturation, the calculations must be made for each separately, for which purpose the preceding values give sufficient data. On account of the diversity of method of operation, only the total consumption is given here.





TABLE 8.

Steam consumption for the saturation with a temperature difference of 18° F. between the juice coming from the heaters and that entering the evaporators, with an average temperature of the escaping gases of 176° F.; 120% draw of juice and the use of milk of lime.

Lime consumption.	j The saturation gas contains per cent CO <sub>2</sub> by volume.									
	14	15	16	17	18	19	20	21	22	23
2.0%	16 10	15.24	14.38	13.78	13.26	12 78	12 34	11 98	11 68	11.40
2.5%	18.25	17.17	16.10	15.35	14.70	14 10	13.55	13 10	12.72	12.37
3.0%	20.40	19 11	17.82	16.92	16 14	15 42	14 70	14.22	13 77	13.35
3.5%	22.55	21.04	19.54	18.49	17 58	16.74	15 97	15 34	14.82	14.32
4.0%	24.70	22.98	21.26	20.06	19.02	18 06	17.18	16.46	15 86	15.30
4.5%	26.85	24 91	22.98	21.63	20 42	19.38	18 39	17 58	16.90	16.27

Lime consumption.	The saturation gas contains per cent CO <sub>2</sub> by volume.									
	24	25	26	27	28	29	30	31	32	
2.0%	11 14	10.92	10.70	10.52	10 34	10.20	10 06	9 92	9.80	
2.5%	12 05	11 77	11.50	11.25	11.05	10.87	10 70	10.52	10.37	
3.0%	12.06	12.63	12.30	11 03	11 70	11.55	11 34	11.13	10.95	
3.5%	13.87	13.48	13 10	12 78	12 47	12 20	11.98	11 73	11.52	
4.0%	14.78	13 34	13 00	13 54	13.18	12.00	12 62	12 34	12.10	
4.5%	15.60	15 20	14 70	14 20	13 80	13 57	13 26	12 95	12.68	

Tables 4 to 8 give the following general results.

(1) For the reduction of the steam consumption it is important to have the carbonic acid content of the gas as high as possible, because with a constant amount of 3% lime at 176° the temperature of the escaping gases

equals a difference of 1.3% for volumetric contents between 25% and 30%  $\text{CO}_2$ ; 3.4% between 20% and 30% and 7.8% between 15% and 30%. The taking of the gas from the rear of wood-fired boilers is handy, but the advantages of the lime kiln lie in the lower steam consumption.

(2) The heat consumption rises with the addition of lime. With a saturation gas of 25% and an escaping gas of  $176^\circ$ , the difference for the addition of 1% lime brings about a difference in steam consumption of 1.7%; with 20% of 2.4%; with 15% of 4.3%.

Therefore, in view of the common acceptance, that a little more lime does not cost much, and, on this account, it is not customary to be economical with this item, we should also exercise control in this direction by means of calculation. As a general thing, it is advisable to use every means to reduce the consumption of lime as much as possible. To such belongs the heating of the juice to at least  $185^\circ$  before the addition of the lime, as also the endeavor to keep the juice as free from pulp as possible, for which purpose its filtration through gravel, coke, or coal screenings would not prove too costly.

(3) The steam consumption increases rapidly with the temperature of the escaping gases and also with the temperature of the juices during saturation. Thus the increase from  $176^\circ$  to  $194^\circ$  with 3% lime and a 25% saturation gas amounts to an increase in steam consumption of  $(4.29 - 1.71)3 = 17.74\%$ , with 15%  $\text{CO}_2$  of  $(9.69 - 3.87)3 = 17.46\%$ .

For that reason, from the viewpoint of steam con-

sumption, it is also important to keep the temperature of saturation as low as possible (just to the point that the presses will run well) and to do the boiling only after final saturation.

Oftentimes this does not suffice, as, for instance, with frozen beets, after stoppage of the battery or the reintroduction of caramelized green syrups, etc., it becomes necessary to boil with lime; then the advantages and disadvantages of these methods of operation must be taken into account.

If there be no special station for the separate treatment of the green syrup and wash syrup which on account of their reintroduction into the process should always be heated up with lime, then the temperature during the saturation of the thin juice must be increased. It is here that steam is uselessly wasted, and for this reason the separate treatment of these products is very rational. This question solves itself very easily and rather judiciously by separate boilings of these products with lime before their introduction into the saturation, in which case with normal beets there is no necessity for boiling until the termination of all saturations.

NOTE. — In the foregoing heat balance the introductions of wash syrup and green syrup into the thin juice saturation are not considered, because they usually reach this station already heated and the steam has, therefore, been expended at another point. If their temperature be lower than that of the juice entering the evaporators, this fact must naturally be taken into account.

EXAMPLE 3. — Four per cent of green syrup of 70° Brix and 5% wash syrup of the same density and of a temperature 54 degrees lower than that of the juice are brought back into the saturation before evaporation. As the heat capacity of a strong solution of about 70° Brix is 0.51, then the steam consumption is:

$$\frac{(4 + 5) 0.51 \times 54}{100 \times 970} = 0.255\%.$$

#### IV. SULPHURATION.

On account of the small quantity of lime which is neutralized by the  $\text{SO}_2$  (if its use be considered at all necessary), there is no reason to make a separate heat calculation for this operation. Should this be desired, then we can assume, that for the sulphuring to the neutral point of a given quantity of lime the volume of gas necessary is equal approximately to that of carbonic acid gas of 15%. For this special case the values determined can be taken into account.

#### V. THE STEAMING OFF OF THE FILTER PRESSES.

The steam consumption is at this point in direct proportion to the amount of lime added, if the filter presses are steamed off. Usually there is obtained 4% cake for each 1% lime. The steaming off is carried on until the steam appears at the outlets, which occurs when the cake and the inner cast-iron parts of the press are heated to 212 degrees. For each 1% lime, on an average, about 20% of cast iron must be heated. If we assume the temperature of the juice and of the iron before steaming off as equal to 176°, the heat capacity of the cake 0.7, that of







the cast iron 0.13, then the steam consumption for each 1% lime is equal to

$$\frac{(4 \times 0.7 + 20 \times 0.13)(212 - 176)}{100 \times 970} = 0.2\%,$$

with a loss on liberation to atmosphere of about 0.25%.

Many, for good reasons, do not steam off, and save this steam.

## VI. THE EVAPORATION.

### A. *The Steam Consumption for Heating the Juice.*

The quantity  $Q\%$  of juice, figured on the weight of beets entering into the evaporation at  $B^\circ$  Brix, is here, before it begins to boil, heated from its initial temperature  $t_0$  to its boiling temperature  $t$ . For this purpose, each 100 pounds of beets with a heat capacity 0.3 of the dry substance of the juice requires the application of heat:

$$Q(t - t_0) \frac{100 - B}{100} + 0.3 Q(t - t_0) \frac{B}{100},$$

or 
$$Q(t - t_0) \frac{100 - 0.7B}{100} \text{ heat units.} \quad . \quad . \quad (6)$$

According to the existing conditions in the first body of the evaporators, the corresponding heat consumption will then be about 954 heat units for each pound of steam,

or 
$$\frac{Q(t - t_0)(100 - 0.7B)}{100 \times 954} \text{ per cent} \quad . \quad . \quad . \quad (7)$$

The value of  $Q$  is made up of the following parts:

*First:* Of the juice which is drawn from the diffusion (100 +  $D$ ).

*Second:* Of the water, which enters the juice with the lime and as sweetening-off water, corresponding to about four times the quantity of lime added.

*Third:* The green syrup and the raw sugar of the second product reintroduced in the process.

From these totals should be subtracted:

*First:* The water evaporated during saturation, which we will here designate by  $V$ , and which can be taken from Table 5 for each 1% CaO; and

*Second:* The sugar and nonsugar which remain in the press-cake and which amount to about 1%.

If these figures, together with the Brix content of the juice and its temperature before and in the first body, be known, then the steam consumption for this purpose is easily determined.

EXAMPLE 4. — The draw of juice is 120%; the addition of lime 3%; the saturation gas contains 25%  $\text{CO}_2$ ; the average temperature of the escaping gas is 176 degrees, the introduction of raw sugar amounts to 3.5%; the green syrup 4%; the juice is 17° Brix, and enters the first body with a temperature lower by 21.6 degrees than that existing therein.

According to Table 5,  $V = 164 \times 3 = 4.92\%$ ;

$$Q = 120 + (4 \times 3) + 3.5 + 4 - 4.92 - 1 = 133.6\%,$$

from which the steam consumption

$$\frac{133.6 \times 21.6 (100 - 0.7 \times 17)}{100 \times 954} = 2.66\%.$$

Hereafter this steam consumption will be considered entirely separate from that which is used for the evaporation proper.





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For rough calculation use can be made of Table 2, estimating approximately the quantity of juice or measuring it directly.

EXAMPLE 5. — Again assume the temperature difference to be  $21.6^{\circ}$  and the quantity of juice entering the evaporators  $130\%$ , then, according to Table 2, the steam consumption for  $20$  degrees =  $2.41\%$ , for  $1.6^{\circ}$  =  $0.19\%$ , then for  $21.6^{\circ}$  =  $2.41 + 0.19 = 2.60\%$ .

### *B. Steam Consumption for the Evaporation Proper.*

The quantity of water which is eliminated in the evaporating station is equal to the difference between the entering thin juice and the outgoing thick juice, but as ordinarily neither the one nor the other is regularly measured, this value must be determined indirectly from the estimated quantity of thin juice and the Brix content before and after evaporation.

EXAMPLE 6. — There is, similarly to Example 4,  $Q = 133.6\%$  at  $17^{\circ}$  Brix; the thick juice is of  $60^{\circ}$  Brix; then its quantity is found from the proportion  $X:Q :: 17:60$ , where  $X = 133.6 \times \frac{17}{60} = 37.85\%$ . Therefore  $133.6 - 37.85 = 95.75\%$  water is evaporated.

The consumption of steam for this purpose depends on:

- (1) The number of bodies.
- (2) How much juice vapor is utilized for the purpose of heating, also from which body it is taken.
- (3) The unavoidable losses due to leaks in the tubes, to drawing off of the ammoniacal vapors and to radiation.

If the first body be considered separately, it can be easily ascertained from Zeuner's table, that, if the con-

densed water flows out at the temperature of the steam, one pound of steam evaporates a little less water, but, if the condensed water goes out at the temperature of the juice, then one pound of steam evaporates slightly more water. As in reality the temperature of the condensed water lies between these limits, we can, in practice, without committing any considerable error, assume that in the first body one pound of steam evaporates an equal quantity of water.

We can say exactly the same thing relative to each following body, if the juice entering it has the same temperature as that existing in the body. But this is not at all the case, because the juice always comes over at the higher temperature of the preceding body and, as soon as it reaches the compartment at a lower pressure, it loses this excess of heat by the evaporation of a part of its water content. For this reason there will always be evaporated more water in the following bodies for a unit quantity of steam.

It would be easy to figure out this excess for any given case, but there are other factors which operate in an opposite sense, namely:

- (1) The losses through leaks in the tubes.
- (2) The radiation.
- (3) The piping for ammoniacal vapors; the steam which enters into the different bodies through the connections for the water drain traps, etc.

These influences cannot all be accurately determined. We will, therefore, assume that they all balance; that in each body a given quantity of steam must evaporate

a similar quantity of water; that in this manner by ordinary triple evaporation one pound of steam evaporates three pounds of water; in a plain quadruple evaporator, one pound of steam evaporates four pounds of water, etc. This assumption has the advantage of simplicity over all other methods of calculation without being any the less accurate.\*

As previously mentioned, the steam consumption, besides depending upon the number of bodies, depends also upon the use of the vapors (juice) for the purpose of heating according to the principle of Rillieux, which establishes the evaporation from a line of  $p$  bodies, as

$$1, 2 \dots m \dots n \dots o \dots p,$$

and takes out of  $m$ ,  $n$  and  $o$  for each 100 pounds of beets  $M\%$ ,  $N\%$  and  $O\%$  of steam for the purpose of heating. If we indicate the quantity of steam which is introduced into the first body for the special purpose of evaporation (without preheating) by  $X$ , then, according to what has been said before,  $X$  will be evaporated in each of the bodies up to  $m$  inclusive and in total  $mX\%$  water in the first  $m$  bodies.

\* As an example of the methods of "exact" people, the following may be mentioned: Some time ago, Jelinek calculated the steam evaporation in a single effect at 0.9, in a double effect at 1.96, in a triple effect at 2.85, in a quadruple effect at 3.79, and in a quintuple effect at 4.72, and this under assumptions taken at random, as for instance, juice temperature 167 degrees and so on. These figures, taken at random, are used today in all texts and manuals, except in the one by Hausbrandt. They are taken as something universally accepted and tables are based on them. Calculations continue to be made according to these random figures, which are simply worthless.



All the succeeding bodies until  $n$  inclusive will evaporate by  $M\%$  less, hence  $(X - M)$ , together  $(X - M)(n - m)$ .

The then remaining bodies up to  $o$  inclusive evaporate still less, namely:  $(X - M - N)$  but jointly  $(X - M - N)(o - n)$ . Each of the succeeding bodies will then evaporate  $(X - M - N - O)$  and jointly  $(X - M - N - O)(p - o)$ . If we call the total of the water evaporated in the entire system  $S$ , then

$$mX + (n - m)(X - M) + (o - n)(X - M - N) + (p - o)(X - M - N - O) = S,$$

and

$$X = M + N + O + \frac{S - mM - nN - oO}{p}. \quad (8)$$

With this formula it is easy to calculate the steam necessary for evaporation.

EXAMPLE 7. — There is to be evaporated in a quintuple effect 96% water; moreover, there is to be taken for different purposes from the first body 8%; from the second body 12%; and from the third body 10% of the steam, then

$$m = 1; n = 2; o = 3, \text{ and } p = 5;$$

$$M = 8; N = 12; O = 10, \text{ and } S = 96; \text{ and}$$

$$X = 8 + 12 + 10 + \frac{96 - 1 \times 8 - 2 \times 12 - 3 \times 10}{5} = 36.8\%.$$

EXAMPLE 8. — In a quadruple effect, 8% steam is taken out of the second and third bodies.

$$S \text{ is here again } 96\%; \text{ and } m = 2; n = 3; o = \text{zero}; p = 4;$$

$$\text{then } X = \frac{8 + 8 + 96 - 2 \times 8 - 3 \times 8}{4} = 30\%.$$





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If the evaporating system has a (single effect) Pauly body, which is fed with direct steam, the calculation is carried on in a similar manner, if the evaporation in the Pauly body has been determined or estimated. It is then only necessary to make the total calculation without the Pauly body and to diminish  $S$  by the amount of the evaporation in the juice boiler  $y$ .

If in the equation (8) we substitute in place of  $S$ , the new value  $S - y$ , then

$$x^1 = M + N + O + \frac{S - y - mM - nN - oO}{p}. \quad (9)$$

$x^1$  means here the total quantity of steam led into the first body of which  $y\%$  comes from the juice vapors of the Pauly body and  $(x^1 - y)\%$  from the exhaust steam.

But as the quantity of juice vapor from the juice boiler is equal to the quantity of direct (boiler) steam entering it (the portion which is used up for heating, as a matter of fact, not being considered),  $x^1$  is equal to the total consumption of boiler and exhaust steam used for the purpose of evaporation.

**EXAMPLE 9.**—A quadruple effect is provided with a juice boiler which evaporates  $8\%$  water. The juice vapor is taken only from the second body to the amount of  $25\%$ . The total evaporation is here again  $96\%$ . How much steam is used?

In the equation (9)

$$M = 25; m = 2; n \text{ and } o = \text{zero and } p = 4,$$

$$\text{then} \quad x^1 = 25 + \frac{96 - 8 - 2 \times 25}{4} = 34.5\%$$

of which  $8\%$  comes in the form of direct steam for utilization in the juice boiler and  $34.5 - 8 = 26.5\%$  as (return) exhaust steam in the first body (mixed with  $8\%$  vapor from the juice boiler).

## VII. THE BOILING.

The quantity of water evaporated in boiling is determined in the same manner as that in the evaporation station.

EXAMPLE 10. — From 37.85% of thick juice of 60° Brix (according to Example 6) there is obtained (without the addition of the second product before dropping) a fillmass of 04° Brix and from an undetermined quantity of second product of 78° Brix, 7% of fillmass of second product at 03° Brix. How much total water is evaporated?

There is obtained  $37.85 \times \frac{60}{94} = 24.16\%$   
of first product fillmass,

therefore, there is evaporated  $37.85 - 24.16 = 13.69\%$   
water while boiling the same.

There must be present  $7 \times \frac{78}{8} = 8.35\%$   
of raw second product, from

which there must be evaporated, out

of the second product, as water  $8.35 - 7 = 1.35\%$   
together then 15.04%

The steam consumption is dependent upon the temperature of the steam, of the condensed water and upon other conditions.

If the temperatures of the thick juice and of the syrup entering the vacuum pan are equal to the temperature of the finished fillmass, and the condensed water goes out at the original temperature of the steam, then the steam consumption with a steam pressure of

0	7.5	15	21.5	30	45	60 pounds per square inch
is 1.04	1.05	1.07	1.08	1.09	1.10	1.12 pounds

for each pound of water evaporated.





If the temperature of the condensed water is lower, the steam consumption is lower than mentioned. For instance, if, in a vacuum pan fitted with serpentine coils, the steam pressure, at the conclusion of the strike, falls from 60 to 30 pounds per square inch, corresponding to a decrease in temperature of  $307.3^{\circ}$  to  $274^{\circ}$ , then the steam consumption for each pound of evaporated water is only 1.08 pounds instead of 1.12. But as there is in every type of vacuum pan during certain periods of the boiling a small loss of heat through the piping for the drain traps, this increase in utilization on account of the drop in temperature need not be further considered.

In addition a certain quantity of steam is used for steaming off the vacuum pans after dropping the strike. This quantity cannot be calculated and varies in widely differing limits according to the water content of the mass and the design of the vacuum pan.

EXAMPLE 11. — For the evaporation of 15.04% of water (see Example 10) out of the first and second products, there is required, at a steam pressure of 45 pounds per square inch,  $15.04 \times 1.1 = 16.54\%$  steam; with the steaming off and reevaporation of the water so introduced, about 17%.

### VIII. THE HEATING OF THE THICK JUICE AND SYRUPS.

The thick juice before filtration and the syrup, which is boiled for the second product, are usually heated, as are also the syrups of second and third products, which are intended for the dilution of the next higher fillmasses.



The steam consumption connected therewith can be easily determined according to one of the previously described methods.

EXAMPLE 12. — There is 37.85% thick juice of 60° Brix (Examples 6 and 10) to be heated through 54 degrees; 8.35% of syrup of second product of 78° Brix (Example 10) to be heated through 72 degrees and about 3% syrup of second and third products of 78° Brix, which are to be utilized for dilution, to be heated through 72 degrees.

The heat capacity at 60° Brix = 0.58, at 78° Brix = 0.45. Therefore, the steam consumption is, when for each pound 954 B.t.u.'s are used,

$$\frac{37.85 \times 0.58 \times 54 + (8.35 + 3) 0.45 \times 72}{954} = 1.63\%.$$

## IX. THE TREATMENT OF THE GREEN SYRUPS AND THE REMELTED PRODUCTS.

Owing to the multiplicity of methods to be applied at this point, there can be given no general rule for the calculation of the steam consumption.

When the heating with lime and a saturation with CO<sub>2</sub> or SO<sub>2</sub> exists, then the calculation may be carried on in the same manner as for the saturation of the thin juice, and the tables there given hold true when the lime consumption is considered in relation to the weight of the beets.

EXAMPLE 13. — 3.5% of raw sugar of second product at 86° and 4% of the higher purity green of 78° Brix and 122° F. are dissolved with about 60% juice of 176 degrees, and then boiled with lime.





## STEAM CONSUMPTION OF INDIVIDUAL STATIONS 39

Since 0.9, 0.45 and 0.3 are the heat capacities of the juice, syrup and sugar, then the steam consumption is

$$\frac{3.5 \times 0.3(212 - 86) + 4 \times 0.45(212 - 122) + (3.5 + 4) \times 1.69 \times 0.9(212 - 176)}{954 \times 100} = 0.46\%$$

If 0.1% CaO be added, in the form of milk of lime, and heated up to 167 degrees, then the steam consumption in addition to this is, according to item C

$$\frac{0.58}{10} = 0.06\%$$

a total of 0.52%

EXAMPLE 14. — Under the conditions adduced in Example 13, with a subsequent addition of carbonic acid of 25%, 0.1% of lime on the weight of the beets is fully saturated at an average temperature of the escaping gas of 194 degrees.

How much steam is used by this saturation?

According to Table 6 the steam consumption for items  $C + D + E - F$  for each 1% CaO = 4.29 for 0.1% CaO, then  $\frac{4.29}{10} = 0.43\%$ , including the heating up of the milk of lime; without this last mentioned heating  $0.43 - 0.06 = 0.37\%$ .

For both operations, according to Examples 13 and 14, then  $0.52 + 0.37 = 0.89\%$ .

## X. THE TURBINATING AND WASHING.

Here the steam consumption varies within wide limits from 0.5% to 1.5% on the weight of the beets, according to the type of centrifugals, their equipment and the method of working.

In reality the consumption ought to be restricted to the dislodging of the air from the centrifugal and to the heating of the sugar and the centrifugal. If the centrif-

ugals were hermetically closed, then indeed would such be the case. The same steam would then be made to re-enter into circulation over the upper free space of the centrifugal (after the sugar and the centrifugal had been warmed up) by means of the centrifugal force exerted from the inside of the centrifugal through the layer of sugar in the basket. In reality the steam runs out into the atmosphere in greater quantities through the drain spouts, and also through the open bottom in the curb of the Weston centrifugals. For the most part, one does not content himself with these losses and arranges the centrifugal casings, with special drain pipes of large dimensions, in the erroneous expectation of thereby accelerating the operation and being less importuned by the steam. The result is clear; the greater the volume of steam induced by this circulation, the more steam must be introduced through the steam valve. If not, the cold outer air will force its way into the centrifugal, thereby retarding the work considerably.

If there be affixed to the outlet spouts of the centrifugal simple hydraulic locking devices or very light valves (which are opened by the discharge), or proper covers on the inner side of the inlet opening, which divert the whirl of the steam from this outlet, then this loss of steam can be brought to amount to *nil*. It is more difficult to close the lower opening of a Weston centrifugal, although this can be done by means of special lift valves.

With such apparatus and with the closing of the ventilating pipes, success has been obtained in accelerating

the work and in diminishing the steam and the heat in the working spaces, and at the same time, in reducing the steam consumption to about half.

The ventilation of the centrifugal is of use only while emptying, as the operator will not then be inconvenienced by the rising steam.

This is accomplished by means of special throttle valves, which are set in the discharge pipes and are opened while the lid is raised.

The encasing of the centrifugal basket serves the same purpose and also serves for the economizing of steam, and this happens contrary to the erroneous idea that the condensation of the steam in the basket does not have any influence on the steam consumption.

From the above it is clear, without further proof, that just as much steam as will be here condensed must be introduced through the steam valve.

## XI. STEAM LOSSES DUE TO RADIATION.

According to Claassen this loss of steam in the boiler and exhaust lines with a fair insulation for an elaboration of 770 tons of beets amounts to 2.49%, and in the steam cylinders to 0.26%.

The losses incidental to the diffusion (from 0.5% to 1%) and to the saturations with the coincident filtrations (about 5.5%) have already been taken into account under the individual stations.

It is estimated that the loss of steam in the evaporators and vacuum pans through radiation is 1.5%, on an average. The heating of the thick juice and of the

syrops which also occasion partial losses by cooling have already been taken into calculation. Wherefore, the losses of steam through radiation not taken into account in the preceding chapters amount together to

$$2.49 + 0.26 + 1.50 = 4.25\%$$

This last figure gives, in conjunction with the losses previously taken into account in the diffusion (from 0.5% to 1%) and in the saturations with filtrations (about 5.5%) and others, a total loss through radiation of from 10% to 12% on the weight of beets, which is sufficiently large to be given weighty consideration. With very good insulation of all pipe connections and fittings, this loss can be diminished; with inadequate insulation, it can be further increased.

For the purpose of judging the relative value of different materials of insulation, the conclusions of Rietschel's researches are very instructive.

For our purpose they are given again, rather converted and somewhat condensed, in the following Table 9.

For the determination of the value of new materials for insulation, one can be guided by the very simple and comprehensive references of Ordway, namely, the lower the weight of a given volume of the heat protecting medium, the greater is the heat protection.

Table 9 shows that cheap felt is the best heat protecting medium. It has only one drawback, namely, that for high pressure steam, it cannot be applied directly on the piping.

For this purpose, Babcock & Wilcox recommend the

TABLE 9.

*Heat Loss if the Loss with Noninsulated Surface be Taken = 100.*

Kind of covering.	Thickness of the layer of covering			
	$\frac{1}{8}$ inch.	$\frac{3}{8}$ inch.	1 inch.	$1\frac{1}{2}$ inches.
Strands of straw covered with clay	69	64	60	57
Wrapping of asbestos yarn with asbestos fibre . . . . .	59	56	54	52
Different preparations of Kieselguhr . .	40	42	40	39
Various kinds of artificial cement preparations . . . . .	38	33	30	28
Cork shavings . . . . .	44	35	29	24
Silk braids without air space . . . . .	25	22	20	19
Carbonized silk . . . . .	25	22	20	19
Felt, soft brown material without covering, or covered and saturated with a solution of dextrine . . . . .	19	16	14	13

wrapping with asbestos millboard, over which, according to the diameter of the pipes, from 6 to 12 wooden staves are laid and fastened with wire. Over this skeleton untarred millboard is wrapped and properly fastened. At the flanges, the spaces between the staves are blocked with wood and the interstices for the bolts subsequently packed with felt. An envelope of sheet tin with a covering of felt over it would give the same or better service.

The following table (10) gives approximately the heat and steam losses for unprotected wrought or cast-iron surfaces. With copper the corresponding values are about one-third lower.



TABLE 10.

*Loss per Hour through Radiation for 1 Square Foot of Wrought-  
or Cast-Iron Surfaces.*

Temperature differences, °F.	B.t.u's.	Steam in pounds.
18	33 2	0 035
36	66 4	0 070
54	107 0	0 113
72	147 8	0 156
90	199 5	0 211
108	251	0 266
126	302 5	0 320
144	362	0 383
162	421	0 445
180	480	0 508
198	535	0 566
216	600	0 645
234	683	0 723
252	746	0 789
270	823	0 871
288	905	0 957
306	990	1 048

In order to ascertain the heat or steam loss per square foot for this or that class of covering it is sufficient to multiply the figures given in Table 10 by the corresponding values in Table 9, and then divide by 100.

Naturally much depends upon how the insulation is applied. For instance, an ordinarily beautiful looking lagging with an air space underneath may sometimes produce harm instead of the desired advantage, as the circulation of the air induced thereby may bring about an increase in heat transference. From this point of view, the felt covering with a thin sheet of iron over it is more rational.

## XII. THE MECHANICAL WORK.

On an average it can be assumed that for an hourly working of 100 pounds of beets 0.67 to 0.82 I.H.P. or 0.55 to 0.67 E.H.P. are necessary.

The steam consumption necessary for one I.H.P. can be approximately taken from Table 11.

For the effective H.P. the steam consumption is about 15% higher. Naturally this table cannot have any very great claim to accuracy in every special case, as the condition of the machinery plays an important part.

Ordinarily the hourly steam consumption varies for an indicated H.P. within limits between 30 and 60 pounds and between 25 and 54% on the weight of the beets.

However large this steam consumption may be, in every average factory the total exhaust steam will be utilized. Therefore, the steam consumption necessary for the production of the mechanical work is not any larger than its theoretically determined value, *i.e.*, one B.t.u. develops 778 foot pounds of work.

The losses of steam incidental to the operation of the machinery due to radiation in the piping, connections and steam cylinders, have already been taken into consideration in the previous chapter.

The consumption of heat for one H.P. hour (= 550 foot pounds in one second) amounts to  $\frac{550 \times 60 \times 60}{778}$

= 2545 B.t.u.'s for 0.67 to 0.82 I.H.P. or 1705 to 2080 B.t.u.'s per 100 pounds of beets. Since this heat is liberated through condensation and as one pound of

TABLE II.  
Hourly Steam Consumption for Each I.H.P. in Pounds.

Pressure difference between the two sides of the steam piston in pounds per square inch.																					
		45				60				75				90				105			
		Diameter of the steam cylinder in inches.																			
Cut-off.		7.9	11.8	15.7	19.7	23.6	7.9	11.8	15.7	19.7	23.6	7.9	11.8	15.7	19.7	23.6	7.9	11.8	15.7	19.7	23.6
		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
0.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
0.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
0.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
0.7	77.2	70.6	64.0	59.5	55.1	68.4	61.8	55.1	50.7	46.3	41.9	37.5	33.3	41.9	37.5	33.3	41.9	37.5	33.3	41.9	37.5

steam of an average of 970 B.t.u.'s, according to the conditions existing in the steam cylinders, is liberated, the steam used up for the performance of the mechanical work amounts then to from  $\frac{1705}{970}$  to  $\frac{2080}{970} = 1.75$  to 2.14% on the weight of beets.

On this point the determinations of different authors vary widely, according to the views each one has as regards the somewhat complex thermodynamic process which takes place in a steam engine.

Jelinek estimated, without reason, the steam which is condensed, when passing through the steam engines, as 30% of the steam entering. A great number of others fell into the error of assuming a special loss of steam due to its expansion beyond the steam cylinder, and the larger, the greater the cut-off of the engine. In this they overlooked the fact that steam expanding into the heating spaces performs no external work as would be the case were the exhaust steam to pass off into the atmosphere.

In reality there exists here, besides those already determined, no further loss of steam; for, if we consider an installation of machinery, joined to a system of heating arrangements, as a whole, we will have here only steam or heat consumption:

1. For the performance of the mechanical work inclusive of the friction losses in the machinery itself, which amount is given by the indicator, and 2. For the radiation. There can be no further heat losses.

Since the best steam-condensing engine of suitable dimensions (in a sugar factory) requires 12 to 15 pounds of steam per I.H.P., or about 10% on the weight of beets, it is plain that the very best condensing engine does not stand comparison with the ordinary type of engine, whose exhaust (steam) is utilized, as the latter consumes only 1.75 to 2.14%, and thus saves about 8% over the former.

As the calculated steam consumption of 1.75 to 2.14% does not depend in any way on the good quality of the engines, it follows that as long as a rational utilization of the exhaust steam is possible, the number and quality of the steam engines have no influence over the total steam consumption, naturally not taking into consideration the difference in the dimensions of the radiating surfaces which can only amount to a fraction of a per cent.

It is almost superfluous to mention that all devices for the superheating of steam in a sugar factory are only of a very restricted value, as the heat and steam consumption for the performance of the mechanical work and for purposes of heating and boiling would not thereby be changed.

If the steam consumption of the engines is diminished, a proportionally greater amount of direct steam would have to be introduced into the evaporators.

If both high and low pressure boiler steam be utilized, the only logical result is that while the utilization of high pressure steam decreases, the demand for low pressure steam increases correspondingly.

In one case one set of boilers is relieved; in the other case it is taxed that much more.

The recent attempt to discover an advantage in the adoption of superheating, because the superheated steam gives off less heat in the piping, is more theoretical than real, since this economy would never amount to 1% on the weight of the beets. For that reason, to install a superheater is surely to follow the wrong course, since there is a possibility, in every factory, to make more remunerative improvements for the same money.

The only advantage in superheating arrangements and modern improved engines lies in the smaller quantity of exhaust steam which they produce.

The smaller the quantity of exhaust steam, the greater the field for a system of utilization of the juice vapors, to which reference will be made later.

### XIII. OTHER STEAM CONSUMING STATIONS.

Besides the stations previously mentioned, there can also be other places where steam is used, such as bone-black houses and filtration, molasses desugarizing processes, heating and ventilation of buildings, etc.

The quantity used in each case must be determined according to special requirements.

We will not concern ourselves further with these processes which are becoming rarer from day to day.

The steam consumption for the Steffens separation is frequently estimated as 15% of the total steam consumption of the factory.

## THE DISTRIBUTION OF STEAM IN THE FACTORY.

### I. METHODS FOR REDUCTION OF THE TOTAL STEAM CONSUMPTION.

Up to the present we have treated of the steam consumption of the individual stations and of the causes influencing it.

Now, we will endeavor to give a general view of the ways and means, which, independently of the steam consumption of the individual stations, have for their purpose the reduction of the total consumption of boiler steam.

As a first means of this kind stands the process of the multiple utilization of the latent heat of steam, first proposed by Rillieux, of which we have already made some mention under the discussion of evaporation.

As there worked out, we established that, if the quantity of water  $S$  is to be evaporated out of the juice, this can be effected by means of manifold evaporation in a number of bodies  $p$ , with an expenditure of only  $\frac{S}{p}$  of steam.

A second not less important process, also brought into practice by Rillieux (the so-called "second Rillieux principle"), consists in substituting in the several heating and boiling stations vapors from one of the evaporating bodies in lieu of boiler and exhaust steam.

Let us now fully investigate what advantage the application of this second principle can offer in each individual case.

Again assume a system of evaporation of any given number of bodies,

$$1, 2 \dots m \dots n \dots o \dots p,$$

out of which a total of  $S$  pounds of water is to be evaporated.

The arrangement is such as to permit of taking out of the bodies  $m, n$  and  $o$ ,  $M, N$  and  $O$  pounds of vapors for utilization in different stations of the factory.

If no use be made of this arrangement, then, as previously stated, there must be applied to the evaporation  $\frac{S}{p}$  and to the other stations  $(M + N + O)$  pounds of steam; therefore, in the system under consideration a total of  $\left(\frac{S}{p} + M + N + O\right)$  pounds.

On the other hand, according to equation (8), page 34, the total steam consumption by the application of Rillieux's principle is

$$M + N + O + \frac{S - mM - nN - oO}{p};$$

therefore, the economy of steam resulting from the application of this principle is equal to the difference between these two totals, *i.e.*,

$$\left(\frac{S}{p} + M + N + O\right) - \left(M + N + O + \frac{S - mM - nN - oO}{p}\right),$$

or, by solving 
$$\frac{mM + nN + oO}{p}. \quad \dots \quad (10)$$



This theorem establishes the fact that the economy of steam through the utilization of juice vapors is equal to the sum of the vapors taken from each body, multiplied by the number indicating its position in the series, divided by the number of bodies in the system.

EXAMPLE 15. — In a quadruple effect there will be taken from the first body (for vacuum pan and saturation) 16%, from the second body (for diffusion and heaters) 14% and from the fourth body (for heaters) 3%.

Then  $m = 1$ ,  $n = 2$ ,  $o = 4$ ,  $M, N, O$ , respectively = 16, 14 and 3, and  $p = 4$ , and the economy of steam is

$$\frac{1 \times 16 + 2 \times 14 + 4 \times 3}{4 \times 100} = 14\%.$$

Were the abstraction of the vapors the reverse, viz., from the first body 3%, from the second 14% and from the fourth 16%, then the economy resulting would be

$$\frac{1 \times 3 + 2 \times 14 + 4 \times 16}{4 \times 100} = 23.75\%.$$

Table 12 gives a synopsis of the total steam economy to be secured for each body by the utilization of vapors from the evaporators.

TABLE 12.

The "Second Principle of Rillieux" gives the Total Steam Saving in per cent of the Consumption in the Stations heated with Juice Vapors.

Evaporating system.	The steam is taken from body					
	I	II	III	IV	V	VI
Single.....	100	.....	...	.....	.....	...
Double.....	50	100	..	.....	.....	...
Triple.....	33.33	66.66	100	.....	.....	...
Quadruple.....	25	50	75	100	.....	...
Quintuple.....	20	40	60	80	100	...
Sextuple.....	16.66	33.33	50	66.66	83.33	100





This table makes it possible, also, to calculate the economy for each case.

In the case of Example 15, the economy in the first body would be  $16 \times \frac{25}{100}$ , in the second  $14 \times \frac{50}{100}$ , and in the fourth  $3 \times \frac{100}{100}$ ; together,  $16 \times \frac{25}{100} + 14 \times \frac{50}{100} + 3 \times \frac{100}{100} = 14\%$ .

If for the evaporation there be utilized boiler steam besides exhaust, the modification of the principle of Rillieux, proposed by Pauly, consists in not introducing it (boiler steam) directly into the first body, but into a special juice boiler or so-called *O* body, Pauly or boiler, the vapors from which together with the exhaust steam are led into the first body and thus used once more.

The saving in steam, which the installation of a juice boiler can bring about, is equal to the difference between the use of direct and exhaust steam for both cases (with and without a Pauly or juice boiler) as is shown, in a general way, in equations (8) and (9), pages 34 and 35.

By subtracting the values in equation (9) from those in equation (8), we find the required steam saving, namely:

$$x - x^1 = \frac{Y}{p}.$$

Therefore, an *O* body or Pauly economizes such a portion of the direct steam introduced into it, as there are bodies in the evaporating system, to which it is connected.

EXAMPLE 16. — A quadruple effect receives, in addition to exhaust steam, 10% of direct steam. Later a Pauly, which received only 8% of direct steam, was connected to this system; then a saving of  $\frac{8}{4} = 2\%$  was effected.

A peculiar method of utilizing juice vapors consists in compressing a part of the vapors coming out of any one body and introducing the same into the first body. This principle was first recommended by Kœrting and it was intended that this compression should be effected by an injector fed with high-pressure steam.

Later Weibel proposed to accomplish this by means of special piston-actuated compressors, which had some justification only where a sufficient quantity of mechanical power was gratuitously obtainable.

Like the Pauly system, this method can be applied only when the condition of the steam engines makes it necessary to furnish the first body continuously with an adequate quantity of direct steam. As a representative of the firm of Kœrting Brothers stated to Dr. Claassen, there are required about 2 pounds of boiler steam at 90 pounds per square inch for the compression of 1 pound of juice vapor from 10.5 to 22.5 pounds per square inch.

The economy to be thereby secured can be ascertained from Table 12. For example, if the vapor be taken from the second body of a quadruple effect, then one economizes 50% of the vapors taken out, etc.

EXAMPLE 17. — Let us again take the case of Example 16. Conditions there are such as to make it possible to give to the first body of a quadruple effect 10% of direct steam. If it is desired, in lieu of this, to use a mixture of one part vapor from the





second body and two parts of live steam (from the boilers), then there is obtained for  $\frac{10}{3} = 3.33\%$  juice vapors,  $2 \times \frac{10}{3} = 6.66\%$  direct (boiler) steam. Now since the vapor taken from the second body (according to Table 12) economizes 50% of its weight, then the economy amounts to  $3.33 \times \frac{50}{100} = 1.66\%$ .

A comparison of this result with the economy (2%), which we figured in Example 16, for the Pauly, shows that the latter affords greater advantages.

The result would hardly vary in favor of compression if the vapors were taken from the third body in lieu of the second, as then the compression of one pound of vapor (juice), owing to its correspondingly decreased pressure, would require much more direct boiler steam.

If there is taken into account the fact that an injector always requires the flow of the full quantity of direct steam (as otherwise, instead of sending juice vapors into the second body, direct steam could easily be introduced) and that the evaporation is of necessity subject to variations, one arrives at the conclusion that the real value of the apparently attractive process is very slight.

## II. THE PRACTICAL ADAPTABILITY OF THE DIFFERENT SYSTEMS FOR UTILIZING JUICE VAPORS.

Having explained the theory of the different systems which have for their purpose the total steam economy, we will proceed to the investigation of the practical adaptation of these principles. But before going further into the matter, we will first tabulate the steam consumption



of the separate stations under average operating conditions, as we have already partly introduced them in the examples. This is done in the following table.

TABLE 13.

Average steam consumption with 120% draw (of juice); heating of the raw juice from 95 to 185°; an average temperature of 176° of the saturation gas with 3% of lime in the form of milk of lime; 25% saturation gas, and other conditions as below outlined.

1. Diffusion (average).....	7.00%
2. Heating of the raw juice.....	10.00
3. Saturation of the thin juice (according to Table 8) .. . . .	12.63
4. Steaming of the filter presses.....	.75
5. Heating of the juice to the boiling point in the first body (Example 4, page 30) .. . . .	2.66
6. Evaporation of 96% water (similarly to Exam- ple 6) in a quadruple effect .. . . .	24.00
7. Boiling to grain (Example 11, page 37) .. . . .	17.00
8. Heating of the thick juice and of the syrups (Example 12, page 38).....	1.63
9. Treatment of the green syrup and wash syrup (Examples 13, 14, pages 38 and 39).....	0.89
10. Turbinating .. . . .	1.00
11. Radiation .. . . .	4.25
12. Mechanical work .. . . .	2.00
Total with a complete utilization of the exhaust steam... ..	83.81%

By the use of a triple effect the steam consumption necessary for evaporation, instead of 24, would have been  $\frac{96}{3} = 32\%$ , with a double effect  $\frac{96}{2} = 48\%$  and the total steam consumption as above would have been, respectively, 91.82% and 107.82%.

Through the incomplete utilization of the exhaust steam there arises a corresponding demand, which would also be greater in the case of thick juice of lower density and of other variations, increasing the steam consumption of the individual stations.

With all possible combinations of steam distribution which have for purpose the diminishing of the total steam consumption above calculated, we must always have in view the temperatures up to which the heating must be brought, as also the temperatures of the steams with which this is to be accomplished, for we can only heat with advantage if a minimum temperature difference of about  $18^{\circ}$  is obtainable.

The higher the temperature of the vapors in the several evaporating bodies, the wider is the field of their adaptability; the higher the temperature to which the heating must be carried, the higher must be the pressure of the steam entering into use.

As the economy of steam is greater in proportion to the stages of evaporation through which the heating steam has already passed before its utilization, the difficulties to be contended with in the utilization of the juice vapors are clearly to be seen.

In order to push the economy of the total steam as far as possible it is necessary:

*First:* To so construct the several heating devices that they can attain their purpose with the least possible temperature difference, for which one employs the largest possible heating surfaces, to accelerate the circulation of the juices to the utmost, especially close to the heating

surfaces; to offer the greatest cross section to the (heating) steam; to replace heating coils by bundles of tubes, etc.

*Second:* The temperatures in the first, second and occasionally also in the third body, as long as the possibility of caramelizing does not dictate otherwise, must be kept as high as possible, achieved by enlarging the first body at the expense of the last, provided this is not accompanied by a too costly enlargement of the entire plant.

As Claassen has proved by experiment, it is profitable, in order to have the total heating surface as small as possible, to have the heating surface in the first body as large as possible in comparison with the last. Latterly, Willaime has sought to demonstrate that this was not the case to the extent stated by Claassen.

Even if the last claim had a slight justification, Claassen's conclusions remain authoritative for practice, for, in the first place, the field for the employment of the vapors is greater and, in the second place, it follows that the calorizators, heaters, etc., which are heated with juice vapors may be made correspondingly smaller.

In spite of all of these considerations the task of the rational arrangement for evaporating and heating becomes very complicated.

On the one hand, greater steam economy must be sought; on the other hand, other extremes, such as sugar losses and the amortization of too costly investments which can overstep the economies in fuel, should be avoided.

A formula which embraces the mathematical relation between all these factors — including the price of fuel, sugar and heating surfaces — has not yet been given and we will not concern ourselves with it, as ultimately we would surely be lacking some coefficients.

We will restrict ourselves to the consideration of a few general points of view, which will at least permit us to avoid more serious errors.

To this end, we will first investigate which maximum temperatures we can have at our disposal in the individual bodies, in order to determine their utilization at the separate stations.

### III. THE DISTRIBUTION OF TEMPERATURE IN THE EVAPORATING SYSTEM.

The density of the juice in the different bodies will first be determined, and for this purpose let us turn back to Example 6, which conforms to the average conditions of operations that have been under consideration. Assume that the juice enters into the evaporation at  $17^{\circ}$  Brix and leaves it at  $60^{\circ}$  Brix. As will be seen further on, in a factory with extensive application of vapors, more than 40% of the total evaporation occurs in the first body of a quadruple effect; with a juice boiler, inclusive of the same, up to about 50%; in the second body about 35 to 40%, and the remaining 10% to 20% are divided between the third and fourth bodies. Simple calculation shows that with such a distribution the density of the juice in the first body will be about

25° Brix, in the second body about 45° Brix, in the third body 50° Brix and in the fourth body 60° Brix.

As is well known, the boiling temperature increases with the density of the juice. Thus, with juice at 25° Brix, this temperature is only about 1° higher than the boiling temperature of water; at 45° Brix this difference amounts to only 3.2°; at 50° Brix to 4° and finally at 60° Brix to about 6.3°.

The temperature of the vapor rising out of the liquid will not be influenced at all by this increase; it always remains equal to the boiling temperature of water corresponding to the then existing steam pressure.

The figures mentioned, 1°, 3.2°, 4° and 6.3°, are entirely useless losses of heat which are occasioned by the temperature difference between the boiling juices and the vapors escaping therefrom. This difference will be increased by the influence of the head of juice above the heating surface.

As everyone knows, the vapors which form from the liquid at a given height must have an increased tension due to the pressure from the column of the liquid, and thus a correspondingly higher temperature than at the heating surfaces. In order to make possible the creation of the vapor the liquid must be heated up that much more at the heating surface.

For this drop in heat this temperature difference is also unprofitably expended.

This loss increases with the vacuum independently of the column of juice and its density. For example, with an average head of juice of 12 inches in the first and

second bodies, corresponding to a head of water of 13 and 14 inches respectively, at a pressure which differs little from that of the atmosphere, this loss is about  $1.8^{\circ}$ ; in the third body, corresponding to a head of water of 15 inches, at a temperature of  $167$  to  $176^{\circ}$ , this loss is  $3.6^{\circ}$ ; and in the fourth body, with 15.5 inches and  $60^{\circ}$  Brix, this loss is about  $7.2^{\circ}$ .

As another cause for this drop in heat, we must consider also the friction in the connections, juice catchers and heating chambers; and lastly, as a fourth cause, the loss of pressure which arises especially in the final piping of the last bodies, because the temperature of the vapor does not exactly correspond to the pressure, which is indicated by the vacuum gauge as existing, since there is mixed with the vapor at this point a certain quantity of uncondensable gases, against which a part of the pressure is exerted. The real tension of the vapor and its corresponding temperature are therefore somewhat lower.

The loss in temperature dependent upon these two conditions cannot be correctly estimated and probably amounts on an average to less than  $1.8^{\circ}$  for each body.

In this manner the total loss in the first body amounts to about  $4.5^{\circ}$ , in the second to  $7.2^{\circ}$ , in the third to  $9^{\circ}$ , in the fourth to between  $14^{\circ}$  and  $16^{\circ}$ , and in total to about  $36^{\circ}$  for all four bodies.

After this explanation, the work of each body individually will be considered.

**Juice Boiler.** — The high temperature of the boiler steam could here secure practically any desired tempera-

ture. It is only necessary not to exceed the temperatures which occasion caramelization. The investigations of Professor Herzfeld show that even at  $248^{\circ}$  the sugar destruction is not very great. If the juice boiler or heating body were so constructed that the juice would have to remain in it only about one minute, an objection could hardly be made to this temperature.

Unfortunately, in practice, this effort towards limiting the juice space is not noticeable and, therefore, an effort is made to secure a juice temperature as far below  $240^{\circ}$  as possible.

**First Body.** — In practice one meets with temperatures in the neighborhood of  $220^{\circ}$  and not over  $230^{\circ}$ . Owing to the large dimensions which it is necessary to give to the first body, it would be desirable not to exceed this last-named temperature. This is permissible only where properly constructed vertical evaporating bodies with a minimum juice space are at hand. With the usual horizontal evaporating apparatus it is better to operate with a temperature not over  $221$  to  $223^{\circ}$ . With a useful drop in temperature of  $7.2$  to  $9^{\circ}$  and a heat loss of  $4.5^{\circ}$ , as calculated by us, the heating steam must be warmer by  $11.7$  to  $13.5^{\circ}$ , which corresponds to a difference in pressure of about 6 pounds per square inch. In cases where the condition of the engines does not permit to maintain a correspondingly high pressure in the exhaust system, the pressure in the first body must naturally be lowered.

**Second Body.** — The resulting temperature of the juice vapors in the second body depends on the temperature

of the juice vapors in the first body and the dimensions of the heating surfaces of the second body.

The higher the temperature in the first body and the larger the heating surface of the second, the less the difference in temperature between the first and second and the higher the temperature in the second. Based on the investigations of Claassen we know that with temperatures in the vicinity of  $212^{\circ}$  a useful drop in temperature of  $9^{\circ}$  still assures a good coefficient of heat transmission.

With these figures as a basis, and by adding thereto our estimated temperature loss of  $7.2^{\circ}$ , we find that the temperature difference between the first and second bodies must not be kept below  $16.2^{\circ}$ . In the second bodies of evaporating systems constructed for proper utilization of juice vapors, one finds for the most part a pressure of 0 or a low vacuum up to 5.92 inches mercury, with a temperature of 199.4 to  $212^{\circ}$ .

**Third Body.** — In this body the useless losses in heat already reach as high as  $9^{\circ}$ . If we assume with Claassen the necessity of maintaining a useful drop in heat of about  $14.4^{\circ}$  here, we find that the temperature difference between the vapor of the second and third bodies should not be less than  $23.4^{\circ}$ . The temperature in the third body can, therefore, not be over 176 to  $188.6^{\circ}$ .

**Fourth Body.** — With a temperature in the juice vapors of  $140^{\circ}$ , corresponding to a vacuum of 24 inches, and our estimated loss due to drop in heat of  $16.2^{\circ}$ , there remains a useful drop in temperature of  $176^{\circ} - (140^{\circ} + 16.2^{\circ}) = 19.8^{\circ}$ , or of  $188.6^{\circ} - (140^{\circ} + 16.2^{\circ}) = 32.4^{\circ}$ ,



according to which the dimensions of the heating surface of this body must be proportioned.

The preceding considerations have reference to the commonly utilized quadruple effect evaporation. For the purpose of figuring other combinations easily and correctly, Table 14, which gives general data as to the approximate losses by drop in heat with the different number of bodies is furnished. It is to be observed that the total loss (an average of  $7.2^{\circ}$  for each body) increases very significantly with the number of bodies.

TABLE 14.

Unprofitable heat losses in the evaporating systems when using juice vapors for the purpose of heating, with an average column of juice of 12 inches above the heating surface; thick juice of  $60^{\circ}$  Brix and the customary vacuum.

Evaporation system.	Loss in temperature difference, degrees F.					Total.
	The individual bodies.					
	I	II	III	IV	V	
Single . . . .	15 3		. . .	. . .	. . .	15.3
Double . . .	7 2	15.3		. . .	. . .	22 5
Triple . . . .	5 4	9	15.3	. . .	. . .	29.7
Quadruple . .	4.5	7 2	9	15 3	. . .	36
Quintuple . .	4 5	5 4	8 1	10.8	15.3	44.1

Having ascertained the limits of temperature of the juice vapors with which we must deal in the different bodies, we can proceed to solve the question as to the steam with which this or that station should be heated.

#### IV. THE LIMITS OF TEMPERATURE FOR THE HEATING STATIONS WITH REFERENCE TO THE ADAPTABILITY OF JUICE VAPORS.

**Diffusion.** — Average steam consumption 7%. The highest temperature which is brought into use is about 185°; ordinarily 177.8 or 179.6° is reached; very exceptionally 188.6°. If this temperature is compared with that of the juice vapor from the third body of a quadruple effect, it is evident at once that there can be no argument in favor of using the same here.

It is most reasonable, therefore, to calculate the heating surfaces of the calorizers for heating from the second body, whereby, according to Table 12, a total economy of  $7 \times \frac{50}{100} = 3.5\%$  of steam is obtainable, as against which heating from the first body would give only  $7 \times \frac{25}{100} = 1.75\%$  or exactly half.

In order to make possible the heating of the diffusion from the second body, it is necessary to have calorizers of sufficiently large dimensions and a minimum temperature difference of not less than 18°.

**Heaters.** — Average steam consumption 10%. The heating is effected mostly from 95 to 185°. If it be desired to utilize only one kind of heating steam, then the heating from the second body is the most advantageous. Since the possibility is here present of carrying on the heating in stages through several units, the first heating up to about 122° can be effected from the fourth

body and the remainder successively from the third and second. Manifold pipe connections, heating units, water drainage and fittings are here necessary and these complicate and increase the cost of the plant to such an extent that the advantage gained often becomes illusory.

The oft-endavored attempt at successive heating from third, second and first bodies is unquestionably unprofitable, since the total of the benefits to be so derived,  $\frac{75 + 50 + 25}{3 \times 100} = 50\%$  only, merely balances exactly that benefit, which can be obtained at much lower cost and less trouble by exclusive heating from the second body.

If it be further taken into consideration that the destruction of sugar, due to the bacteria present in the diffusion and measuring tanks, increases more easily in heaters fed with vapors from the fourth body, and even occasionally here reach their extreme limit, and that at times the drainage of the condensed water from a heating chamber under a vacuum of from 23.8 to 25.5 inches does not always take place readily, it will generally be discovered that the exclusive heating from the second body is most appropriate.

Only with very costly fuel can it be recommended to bring into use the succeeding bodies.

If one-third of the heating were effected from the fourth body and two-thirds from the second, the economy of steam then would be  $\frac{100 \times 1 + 50 \times 2}{3 \times 100} = 66.7\%$ .

Were the heating carried on in equal parts from the third and second bodies, the advantage is almost the same, namely:

$$\frac{75 + 50}{2 \times 100} = 62.5\%.$$

**Saturation.** — Steam consumption 10 to 15%. The lowest temperature at which saturation is for the most part carried on is about 176°. It, therefore, can not be heated from the third body. On the other hand, as the temperature must rise up to 194° and above, between the first and second saturation, and, after complete saturation, up to 212°, there can also be no question as to exclusive heating from the second body.

For the first saturation, due to radiation and also to the practice of heating while the gas is being introduced, and, moreover, owing to the turbid condition of the juice in the tanks, this is possible only with heating coils; it appears that the utilization of direct steam is inevitable at this station.

Therefore, the method resorted to by Nogaczewski, which consists in continuously taking the juice out of the tank while saturating, and returning it to the juice spaces of the tank through a special heater, by means of a centrifugal pump, appears very rational.

For this purpose, juice vapor can be used at will, and the foam is broken down by means of the flow of juice.

As the heating of the first saturation is not commonly carried beyond 185°, this can be done very well with vapors from the second body.

The heating of the second and third saturations

depends too much upon the methods of operation taken into consideration, which can be manifold. For this reason, it is not possible, therefore, to give here any definite formula for the heating. In general, 60 to 70% of the heat necessary for saturation can be taken from the second body according to Nogaczewski, and the remainder made up from the first body or in extreme cases with direct steam.

For the most part the entire saturation is found to be carried on with direct steam.

**Boiling.** — The steam consumption according to the density of the juice is here from 16 to 20%.

The maximum temperature of the massecuite during the building up of the grain is about 185°; only with massecuites containing raffinose and with second products does it now and then go higher.\*

During the remainder of the time the temperature is generally lower.

There would also be no objection to use here the vapors from the second body if the pressure of the massecuite on the heating surfaces did not so oppose.

In modern vacuum pans, the average height of the massecuite above the heating surface is 3 feet at the beginning of the boiling and at the close sometimes 10 feet high.

With the density of the massecuite 1.5, this is equivalent to a pressure of 4.5 feet of water at the beginning and 15 feet at the finish; and this is equal to a rise in

\* In a factory operating with the Strontian process, I have seen the graining occur at 212°.

absolute pressure of 6 inches of mercury at the surfaces, and, according to Flegner's tables, a rise in temperature of 21.6 to 50.4°.

If these degrees are added to the temperature above mentioned, it is evident that in the modern vacuum pans there can be no question as to heating from the second body, especially so since the heating from the first body introduces considerable difficulties and this conclusion is also verified in practice.

In all modern vacuum pans which are provided with arrangements for heating from the first body, the upper coils only or heating drums are used for this purpose.

As long as the film on these heating surfaces is thin, they will take up juice vapors fairly well, although the lower sections, partly fed with direct steam, work much more energetically, at which point the useful drop in temperature is several times greater.

As the boiling process goes on and the level of the mass over the heating surface increases, the temperature of evaporation next to the heating surface rises, and with it the already low temperature drop of the upper surfaces becomes equal to nothing and the whole remainder of the work is carried on with direct steam.

Thus it happens that the portion developed from the juice vapor amounts to less than half of the total work (in most cases to only one-quarter) in spite of the fact that the heating surface for juice vapor is often very large.

But as the economy to be secured by heating from the first body of a quadruple effect amounts to only 25%,

it follows that the total benefits to be derived amount at most to 2%, and very frequently only to 1% steam on the weight of the beets, which seldom offsets the additional expenditures for such installations, so much more so that the dimensions of the apparatus and the pipe connections increase, and further losses are occasioned by radiation.

The advantages of heating from the second body would naturally be lower.

From this it is evident that there is a possibility that apparatus will be constructed in the future which will boil to grain by using juice vapors exclusively from the second body, which would correspond to an economy of steam of about 8%.

#### V. DIAGRAMS FOR THE DISTRIBUTION OF STEAM.

There still remains for us to give a few diagrams for the distribution of the steam, which encompass and elucidate our previous determinations.

For this purpose, we will turn back to the conditions of operation which are tabulated in Table 13, page 56, wherein we will combine the steam consumption for the smaller items 4, 5, 8, 9, 10, 11 and 12 under one common figure, 13.18%.

DIAGRAM 1. — A factory is fitted with a quadruple effect and all stations are heated with boiler and exhaust steam.

## 71

Diffusion.....	7.00%	
Heaters.....	10.00%	
Saturation.....	12.63%	
Vacuum pans....	17.00%	
Sundries (4, 5, 8, 9, 10, 11, 12)..	13.18%	
Evaporation....	24.00%*	I → II → III → IV → 24%
Total .....	83.81%	

to condenser.

24
24
24
24

Water evaporation, 96%.

<b>Boiler and Exhaust Steam Consumption:</b>			<b>7<math>\frac{1}{2}</math>% Diffusion → 10% Heaters.</b>	
Saturation . . . . .	12.63%			
Vacuum pans . . .	17 00%			
Sundries (4, 5, 8, 9, 10, 11, 12) . .	13 18%			
Evaporation . . . .	32.50%*	I	II	III
Total . . . . .	75.31%	IV	V	to condenser.
		32 5	32 5	15 5
		Water evaporation, 66 $\frac{1}{2}$ %.		

\* Here, as in all the following diagrams, this figure expresses only the steam which is really utilized for evaporation. That portion which is used for heating in the first body or, in other words, as a juice boiler, is, according to line five of Table 13, included in the 2.66% under the heading of "Sundries." This value must always be added to that given for the juice boiler or for the first body, if one take into consideration the steam entering into either when calculating the vapor pipes.



DIAGRAM 3. — Juice vapor is used as follows: from the first body, 7% for the vacuum pans; from the second body, 7% for diffusion, 10% for heaters and 7% for saturation.

Boiler and Exhaust Steam Consumption:						
Saturation (12.63-7).....	5 63%					
Vacuum pans (17-7).....	10.00%	7%	7%	10%	7%	
Sundries .. . . .	13.18%	↑	↑	↑		
Evaporation....	41.25%*	I	II	III	IV	to condenser.
Total.....	70.06%					
		41.25 34.25 10 25 10 25				
		Water evaporation, 96%.				

DIAGRAM 4. — The preceding distribution of vapors, but with a juice boiler which consumes 8% of direct steam.

Boiler and Exhaust Steam Consumption:						
Saturation...	5 63%					
Vacuum pans.	10.00%	7%	7%	10%	7%	
Sundries.....	13.18%	↑	↑	↑		
Evaporation. {	8.0 %*→	I	II	III	IV	to condenser.
	31.25%	8				
Total.....	68.06%					
		8 39.25 32.25 8.25 8.25				
		Water evaporation, 96%.				

\* See note under diagram 1.



DIAGRAM 7.— From the second body of an ordinary quadruple effect, juice vapor is taken for diffusion and heaters; also 7% for saturation and 16% for vacuum pans. This combination will be possible only when the sugar industry has at its disposal appropriate vacuum pans permitting at the same time the carrying on of the rest of the work with the poorest engine arrangement.

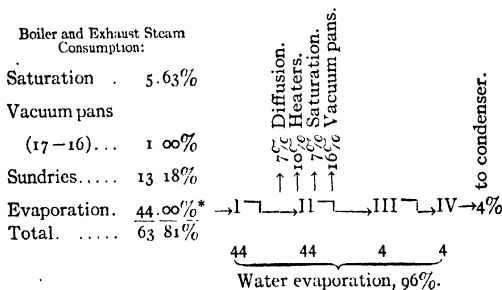
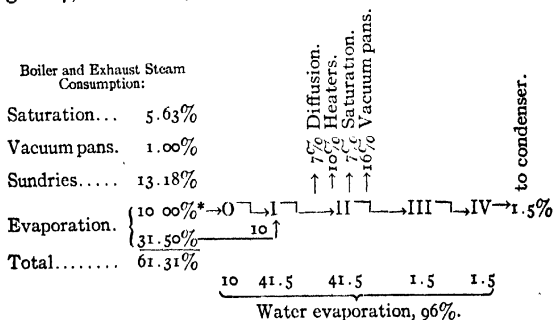


DIAGRAM 8.— The same distribution of vapors as in diagram 7, but with a juice boiler which receives 10% vapors.



This diagram demonstrates that with a juice boiler with abundant utilization of vapors the work of the last

\* See note under diagram 1.

# DISTRIBUTION OF STEAM IN THE FACTORY 75

two bodies is not to be considered at all. Therefrom arises the idea of omitting them altogether.

DIAGRAM 9. — The same as the preceding example, but without the third and fourth bodies; the second body having such a low vacuum that the heating of the total number of stations is possible.

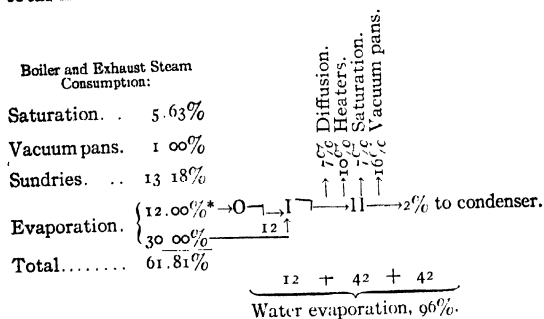
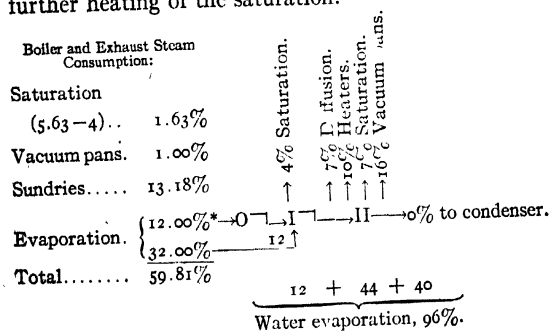


DIAGRAM 10. — The same as the preceding example, but with the taking of 4% from the first body for the further heating of the saturation.



\* See note under diagram 1.

**DIAGRAM 11.** — With well-designed and properly operating engines and a high steam pressure, according to the preceding example, the juice boiler ("O" body) can be taxed harder, as the exhaust steam under favorable conditions can drop down to 20%; but inasmuch as, in this case, the total quantity of vapors developed in the second body might not suffice for all purposes, then of the 16% (which, according to diagram 10, the second body should furnish for the vacuum pans), 10% is carried over to the first body which further facilitates the practicability of such arrangement.

Boiler and Exhaust Steam Consumption:					
Saturation	1.63%	Saturation. Vacuum Pans.			
Vacuum pans.	1.00%	4% 10% 7% 10% 7% 6%			
Sundries	13.18%	↑ ↑ ↑ ↑ ↑ ↑ Diffusion. Heaters. Saturation. Vacuum pans.			
Evaporation	$\left\{ \begin{array}{l} 22.00\% \xrightarrow{*} O \rightarrow I \rightarrow II \rightarrow 0\% \text{ to condensér.} \\ 22.00\% \xrightarrow{\quad\quad\quad} 22 \uparrow \end{array} \right.$				
Total	59.81%				
		$\underbrace{22 + 44 + 30}_{\text{Water evaporation, 96\%}}$			

If the practicability of a system utilizing the vapors for the purpose of heating the vacuum pans from the second body is indeed a question of moment, then the following example is in accordance with the present practice. There arose in a factory producing from 25 to 30% exhaust steam, equipped with a triple effect, the prob-

\* See note under diagram 1.



The diagrams show that, with a juice boiler and sufficient utilization of the heating vapors from the juice, a quadruple effect does not by any means give better results than a double or triple effect system.

The difference lies in the fact that, with a double-effect system, one would be compelled to complete the thickening of the juice at about  $203^{\circ}$ ; which fact, with the customary construction of the evaporating apparatus, would involve somewhat larger sugar losses. These, however, could be very much reduced by the greatest possible reduction of the juice spaces.

The reduction of the spaces taken up by the juice, by one-half, or one-third, contrary to common practice, does not appear to be especially difficult with vertical evaporating bodies.

Too often, indeed, there is seen in practice altogether absurd efforts, and many a leading firm turns the heads of the people with so-called improved vertical evaporating bodies with juice circulation through the center and around the heating chambers; as also with horizontal bodies, with heating elements, which are composed of chambers containing bundles of expanded tubes set crosswise to each other. The one, as also the other, constitutes an altogether foolish retrogression, as such arrangements, without even giving anything positive, greatly increase the juice content.

Naturally, the considerations concerning the adoption of a double-effect system with a very low vacuum in the last body is, at present, a vision of the future; but since there is set before us the problem of making

plain the theory of steam economy in the sugar factory, to show the way by which one can progress towards securing still better results is not to be ignored.

That, for this reason, one must not expect, by any means, to limit himself to the vertical evaporating bodies is self-evident.

Perhaps it may be recommendable to once more revise the principle of film evaporation, which, if properly used, would give good results. Until the present day it has not been seen what advantages this could offer over the old system since no more is secured from the increased transference of heat through an induced circulation.

These advantages can be realized whenever it is a question of reducing the period of evaporation to a minimum and to diminish the useless losses of drop in temperature.

It should not be forgotten that the diagrams for the utilization of vapors conform with an altogether determined method of operation, under average conditions.

The use of dry lime instead of milk of lime would reduce it about 2.5 to 3.5%. Diminished draw of juice for the diffusion, less lime, the elaborating of raw sugar, etc., would further economize 10% vapor and more. Concerning these, some data are given in the following chapter.



THE INFLUENCE OF THE METHODS OF OPERATION OF THE SEVERAL STATIONS ON THE TOTAL STEAM CONSUMPTION.

Having laid down in previous pages the leading principles, which are of importance for the proper management of steam in a sugar factory, we can consider our object as accomplished; but, for the sake of completeness, we will discuss a few more questions which frequently come to the mind of a technical sugar man, from the standpoint of steam consumption.

(1) What is the loss occasioned by a small diffusion through excessive draw of juice; what economy would a large diffusion effect?

In order to answer such a question, it is necessary to go from the diffusion through all of the succeeding stations. Let us do this and see afterwards at which points and to what extent each 10% increase of juice draft (for the diffusion) will affect the steam consumption.

**Diffusion.** — Table 1 shows that the steam consumption for the diffusion not only does not fall with the diminution of the draw, but on the contrary under usual conditions of operation (where the temperature of the diffusion water is higher than the temperature of the juice) even rises somewhat.

Moreover, the losses through radiation in a larger diffusion are inevitably larger.

At this station the steam consumption also increases somewhat with the enlarging of the battery.

**Raw Juice Heater.** — Table 2 indicates that the diminution of the juice draw by 10%, with the customary heating through 90°, reduces the demand for heat by about 0.8%.

**Saturation.** One can easily see that all the items which have been placed together in their proper places (pages 17 to 20) under the headings (*B*), (*C*), (*D*), (*E*) and (*F*) do not depend in any way upon the draw; this last will have influence only on item (*A*). For the saturations, the average temperature difference between the juice which enters into the first saturation and that which goes into the first evaporating body is about 18°. Every additional 10% of water occasions, therefore, an increased expenditure of steam in the ratio of  $\frac{10 \times 18}{970} = 0.185\%$ .

**Evaporation.** — For a quadruple evaporation, each additional 10% water occasions an increased use of  $\frac{10}{4} = 2.5\%$  steam; correspondingly more with a less number of bodies.

ALL OTHER STATIONS occasion no increased expenditure, provided the evaporating station is large enough to deliver at all times a juice sufficiently thick.

If we add together all the items specified, we find that, with a quadruple effect and with the use of boiler and exhaust steam for heating and saturation, for every 10% increase in draw a total of 3.5% increase in steam will be expended.

If the heaters be heated from the second body, the

increased expenditure here falls off by 50%, that is, from 0.8 to 0.4% and the total utilization from 3.5 to 3.1%.

Naturally, in carrying on the diffusion, sight must not be lost of the biological sugar losses, since these grow in exact proportion to its duration.

(2) How does the use of a lime kiln, instead of taking the saturation gas from the smoke flue of a wood-fired installation, influence the steam consumption?

This influence is to be seen directly from Table 8, as it gives clear data relative to the steam consumption for varying qualities of gas and additions of lime, if the average temperature of the escaping gases be 176°.

For example, the change from 15% gas to 28% gas, with 3% lime, gives an economy of  $19.11 - 11.76 = 7.35\%$ .

For other temperatures a correction must be made according to Table 6. For example, this table gives for each 1% lime between 176° and 167°, with 15% CO<sub>2</sub> a difference of  $3.87 - 2.73 = 1.14\%$ ; with 28% CO<sub>2</sub>,  $1.42 - 1.00 = 0.42\%$ . With 3% lime the difference between 176° and 167° would amount to  $(1.14 - 0.42) 3 = 2.16\%$ .

At 167° the economy would be equal to  $7.45 - 2.16 = 5.29\%$ .

(3) How will the steam consumption be affected by the addition of 1% of lime?

The result of adding one more part of lime to every 100 parts of beets makes itself felt in an increase of steam consumption in the saturation itself, as also in the necessity for evaporating more water in the evaporation system.

**Saturation.** — This question is answered in Table 6, which indicates, for instance, that at 176°, according to

the quality of the gas, this steam consumption for 1% of lime with 30% carbon dioxide gas amounts to 1.28%; with 25% gas, to 1.71%; with 20%, to 2.42%; and with 15%, to 3.87%.

**Evaporation.**—With each 1% of lime there will be introduced 4% more water which will consume, for its evaporation in a quadruple system, 1% of steam. In total, therefore, at 176° and with 30% CO<sub>2</sub>, each 1% of lime increases the steam consumption by 2.28%; with 25% gas, by 2.71%; with 20% gas, by 3.42%; and with 15% gas, by 4.87%.

(4) How does the steam consumption change with each 9° difference in the average temperature of the saturation juice?

This question is answered in Table 6, by multiplying the difference between the two values set under one another by the percentage of lime, and reducing the product, for a quadruple effect, by 25%, because the evaporation of each 4% water in the saturations diminishes the steam consumption by an evaporation equal to 1%.

For a triple evaporation the product must not be reduced by 25% but by 33.3%.

In this manner, with 25% of gas and 3% of lime, the change in the temperature of the saturation gas from 185 to 176° in a quadruple system saves

$$(2.56 - 1.71)3 \times \frac{75}{100} = 1.91\%$$

with a change from 176 to 167°,

$$(1.71 - 1.20)3 \times \frac{75}{100} = 1.15\%$$

Were the saturations heated with juice vapors, the economy would also diminish correspondingly.

(5) How much more total steam would be expended for the saturations by the use of perforated coils, in lieu of serpentine coils or steam heating drums?

The consumption of steam for the saturation itself remains practically unchanged whether the heat is secured through open coils or through serpentines; but, with the open coils, the whole of the condensed water goes into the juice and must then be re-evaporated with an expenditure, in a quadruple effect, of one-fourth of the total quantity of steam used in the saturation, and in a triple effect of one-third. In the saturation carried on with open coils the utilization of 14% of steam occasions an increased consumption of  $\frac{14}{4} = 3.5\%$  in a quadruple effect and  $\frac{14}{3} = 4.67\%$  in a triple effect.

Naturally, this greater consumption can be correspondingly increased if more moist steam is used and there enters into the juice with it much previously condensed water. If, therefore, conditions compel the use of open steam coils, care should be taken that the steam be drawn from the driest point of the pipes (not towards the end of a steam header) or, what is still better, that it be previously passed through a steam separator.

(6) How much higher is the total steam consumption with the use of open steam coils for the heating of the thick juice and the syrup?

If the vacuum pans are heated exclusively with boiler

(direct) steam, it will be necessary to re-evaporate here the surplus water introduced with an expenditure of 1.1% steam for every 1% of water. The heating with open steam coils proves to be here a very expensive method. By the utilization of juice vapors for boiling, this increased expenditure is correspondingly diminished.

(7) How much higher is the steam consumption with the use of open coils for heating of the wash syrup and the green syrup which are returned into the first product?

The answer to this question is given in the solution of questions (5) and (6), according as these products are introduced either in the thin juice previous to the evaporating station, or in the thick juice after that station.

(8) How does the consumption of the steam vary if, instead of thick juice of 60° Brix, juice of 50° Brix or 40° Brix be introduced for boiling?

In accordance with Example 6, page 31, we would get under the average conditions of work 37.85% of thick juice of 60° Brix.

Were it pumped out of the evaporators as thick juice of 50° Brix, there would be a greater volume of it, namely:

$$37.85 \times \frac{60}{50} = 45.42\%$$

The vacuum pans would, therefore, have 45.42 - 37.85 = 7.57% more water to evaporate, which would amount to an expenditure of steam of  $7.57 \times 1.1 = 8.33\%$ .

On the other hand, the evaporating station being of the quadruple system for 7.57% of water would con-

sume  $7.57 \times \frac{25}{100} = 1.89\%$  less steam, so the total steam consumption is only  $8.33 - 1.89 = 6.44\%$  higher.

$40^\circ$  Brix would make the total quantity of thick juice  $37.85 \times \frac{60}{40} = 56.77\%$ , and the vacuum pans would have  $56.77 - 37.85 = 18.92\%$  more water to evaporate and that with an increase of  $18.92 \times 1.10 = 20.81\%$  steam. But as the evaporating station consumes  $18.92 \times \frac{25}{100} = 4.73\%$  less, the total expenditure is  $20.81 - 4.73 = 16.08\%$ .

Were the vacuum pans heated exclusively from the second body, the increased expenditure would amount to only one-half.

#### CALCULATION OF THE HEATING SURFACES.

After having decided upon the proper diagram to be selected for the distribution of the steam — according to the existing local conditions — the calculation for the heating surfaces of the evaporators and for all the heating stations can be considered. In order to do so, the known coefficients of heat transmission (obtained by experiment or through experience) and the drop in heat of each individual apparatus are used, taking care, on the one hand, that the regular function of each is not interfered with, and avoiding, on the other, the possibility of sacrificing other stations considered in the heating combinations.

It is not necessary to mention especially that all these factors can have no direct influence upon the steam con-

sumption, because all deductions are entirely independent of the size of the heating surfaces, their relations to each other, the materials of which they are made or, finally, whether or not they are covered with scale.

Differences in the size of the heating surfaces or in their material and their condition can only bring about other transmission coefficients, or rather the possibility or impossibility of obtaining the desired result or the desired productivity from a given heating surface. Thus, if the desired evaporation or heating is secured, then the steam consumption is entirely independent of all these circumstances.

It is the task of the engineer to proportion all the stations in such a way that with the elaboration desired, the required temperatures will set in everywhere of themselves, so that with given temperatures the necessary heat transference will result. In order to obtain this, only the most simple calculations with the known heat-transference coefficients (easily determined in practice) have to be made, according to the equation:

Heating surface =

$$\frac{\text{number of heat units to be transferred}}{\text{temperature difference} \times \text{transmission coefficients}},$$

in which equation, as a matter of course, the number of the heat units to be transferred and the transmission coefficient have to be brought into relation with one and the same time-unit, usually a minute. Under the heading "temperature difference," the useful drop of heat is to be understood. For the facilitation of such



calculations and also for other purposes, such as the determination of the pipe diameter for steam, water and juice lines, Table 15 can be used to advantage, as it gives the amount of beets which is to be worked up per hour, minute and second for every daily elaboration.

TABLE 15.

Giving the Slicings per Hour, per Minute and per Second, Corresponding to Daily Capacities from 300 to 3000 Tons.

Tons per day.	Tons per hour.	Pounds per minute.	Pounds per second.
300	12 50	416 6	6.94
400	16 66	555 5	9.26
500	20 83	694 4	11.57
600	25.00	833 3	13.88
700	29 16	972 1	16.20
800	33.33	1111 0	18.51
900	37 50	1249 9	20.83
1000	41 66	1388 8	23.15
1100	45 83	1527 7	25.46
1200	50 00	1666.6	27.77
1300	54 17	1805 4	30.09
1400	58.33	1944 3	32.40
1500	62 50	2083 1	34.71
1600	66 66	2222 0	37.03
1700	70 83	2360 8	39.35
1800	75 00	2499 7	41.66
1900	79 17	2638 6	43.98
2000	83.32	2777.5	46.29
2100	87 50	2916 4	48.31
2200	91.66	3055 3	50.92
2300	95 83	3194.2	53.24
2400	100 00	3333 1	55.55
2500	104.17	3472.0	57.86
2600	108.33	3610 8	60.18
2700	112 50	3749.7	62.49
2800	116 67	3888.6	64.81
2900	120.83	4027.4	67.12
3000	125.00	4166.3	69.44





By means of this table it is easy to determine the quantity of juice which is passing this or that station, the quantity of water evaporated in this or that body, the quantity of steam received through this or that line, and so on.\*

EXAMPLE 18. — According to Example 10, page 36, 15.04% water is evaporated in the vacuum pan. How many pounds are evaporated per minute for a daily slicing of 440 tons of beets?

According to Table 15, for this capacity there are 609 pounds of beets per minute, thus  $609 \times \frac{15.04}{100} = 91.6$  pounds of water are evaporated in the vacuum pan per minute.

EXAMPLE 19. — How large must be the heating surfaces of bodies I, II, III and IV if, with a daily slicing of 660 tons of beets, the steam distribution is to be installed according to diagram 7, page 74, assuming a useful temperature drop of 9°, 10.8°, 14.4° and 27°,† and a heat transference of 10.24, 7.17, 4.1 and 2.05 B.t.u.'s per square foot for each degree difference in temperature?

\* The figures for the hourly slicings are well suited for the determination of the diameter of the steam pipes. It is only necessary to multiply the particular number in the table by the percentage of steam passing through the pipe, according to diagram, and to look for the nearest number in the corresponding column in Hausbrand's Table 32. The number of "pounds per minute" is well suited for the calculation of heating surfaces, and the number of "pounds per second" well adapted for the calculation of the water and juice pipes.

† With a total heat drop of 36°, page 61, this corresponds to a temperature difference of 97.2° between exhaust steam and vapors from the last body. Thus, if the expected vacuum is 24.6 inches of mercury, corresponding to 136.4°, the exhaust steam must have a temperature of  $136.4 + 97.2 = 233.6^\circ$ , equal to a pressure of 8.1 pounds per square inch.



**QI**

## (Continued.)

**Total Weight of Steam in pounds, which passes in one hour through pipes from 1 to 36 inches in diameter and 80 feet long, at pressures between 88.2 and 1.058 pounds per square inch absolute with 0.5% loss of pressure.**

<b>Absolute pressure, lbs. per sq. in. ....</b>	10.28	7.35	5.52	3.78	2.87	2.28	1.76	1.058
<b>Absolute pressure, inches mercury .....</b>	21.0	15 0	11.23	7.72	5.86	4 65	3.60	2.16
<b>Vacuum, inches mercury .....</b>	9 0	15 0	18.77	22 28	24.14	25 35	26.40	27.84

<b>Diameter of pipe, inches.</b>	<b>Velocity of steam, feet per second.</b>	<b>The weight of steam in pounds which passes through the pipe in one hour with 0.5% loss of pressure.</b>						
1.0	27.9							
1.2	29.5							
1.4	31.2							
1.6	34.4							
2.0	37.7							
2.4	42.7							
3.15	47.6							
3.54	49.2							
3.97	50.8							
4.72	55.8							
5.90	60.7							
6.90	65.6							
7.88	70.5							
8.86	75.5							
9.85	78.8							
11.80	87.0							
13.75	93.5							
15.75	100.0							
17.70	106.8							
19.70	111.5							
21.65	116.4							
23.60	123.0							
25.60	126.2							
27.55	130.3							
29.50	136.0							
35.40	151.0							



which  $\frac{34,916}{27 \times 2.05} = 635$  square feet (approximately) of heating surface is necessary.

It is hardly necessary to mention that too much stress is not to be laid upon these figures. In the given case it would, perhaps, be better for the machinery builders if they can make bodies I and II of the same size, say of about 4840 square feet, a fact which would cause only small deviation from the normal temperatures. It is also recommended to make the last two bodies alike, say 645 square feet, but it would be much better to make them somewhat larger, in order not to be troubled by the gradual formation of scale. As long as the heating surfaces are clean, it will not be difficult to obtain the desired temperatures in bodies I and II, by closing the ammonia valves in bodies III and IV.

EXAMPLE 20. —How large must be the heater if, with a daily slicing of 440 tons of beets, the raw juice is to be heated from 95 to 185°, using the vapors from the second body with a temperature of about 203°? Let the draw of juice be 120%, the heat transference be 4.5 B.t.u.'s per minute per square foot for each degree difference in temperature. According to Table 15, the slicing of beets per minute is 610 pounds. According to Table 2, in that case, 9720 B.t.u.'s are necessary per 100 pounds beets, then for 610 pounds =  $\frac{610}{100} \times 9720 = 59,300$  B.t.u.'s.

The average temperature difference is calculated from Hausbrand's tables as 50.2°; thus the heating surface must be:

$$\frac{59,300}{50.2 \times 4.5} = 2622 \text{ square feet.}$$



## CLOSING REMARKS.

For a plant which is being operated according to the methods given, there results a steam consumption of about 75% on the weight of the beets, which will drop to 70% (according to diagram 3) with a relatively complete outfit, by the heating of the diffusion and the raw juice from the second body of a quadruple evaporation (diagram 2).

With better machinery, fed with steam of a higher tension, it is possible to feed an "O" body or a "juice boiler" with 8 to 16% of direct steam (diagrams 4 and 5), whereby the steam consumption drops to 68 or 66% respectively. If the vacuum pans are heated exclusively with juice vapors and the utilization of the latter carried to the extreme, it may be possible to apply the Pauly process still further and to get a steam consumption of 60% even with a reduced number of bodies. With the lowest possible draw of juice, with dry lime, and when elaborating raw sugar, the consumption can still be lowered by about 10%. On the other hand, it is clear that with thick juice of low densities, with perforated coils in the saturation, with an incomplete utilization of exhaust steam and similar deficiencies in the whole arrangement and methods of working, the steam consumption can be 100% and over. By reason of these figures, it is not difficult to realize how high the fuel consumption may be.

In all the calculations it is assumed that the condensed waters leave the heating chambers at tempera-

tures approaching that of the steam in them. As, for the feeding of the boilers, only part of this water is necessary, it is by no means difficult to select that portion which is not under  $212^{\circ}$ , for this purpose. Under these conditions, there may be expected an eightfold evaporation, even with average results from a medium grade of coal. Under favorable conditions possible in sugar manufacture (absence of scale in boilers, the possibility of an exact control of operation, the use of compound boilers which permit the highest efficiency), even a ninefold evaporation is not an extremely high result. Therefore, the consumption of a medium grade coal in factories, which are operated according to diagrams 2 to 5, should not surpass 8 to 9%; it can, however, drop to 7 and 8%. With a high grade coal and favorable working conditions, it can drop to 6 and 7%, and with raw sugar production even lower.

It is unnecessary to mention that a well-calculated steam economy is of prime consideration for a sugar factory which is to be constructed, because the cost of manufacture from the beets will diminish, due to reducing the steam consumption, and the building costs will be lower since the size and capacity of the boilers, of the condensers, of the air, water and ammonia pumps, and of the pipe connections will be reduced.

Matters are, of course, different if the utilization of steam is to be arranged in a factory already in existence, because then the expected savings must be compared with the costs entailed, whereby it will often figure out that it is better to use here a rather larger quantity of

fuel, since the best apparatus may prove too expensive. There is still in this line of work in the existing factories a very profitable field for the investment of capital with good prospects for excellent returns. But very often unforeseen conditions will occur which will annihilate the savings through an increased loss of sugar (bacteria with too large a diffusion, etc.). In a few cases it becomes apparent that the control of the sugar loss is for the most part still very unsatisfactory.

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